



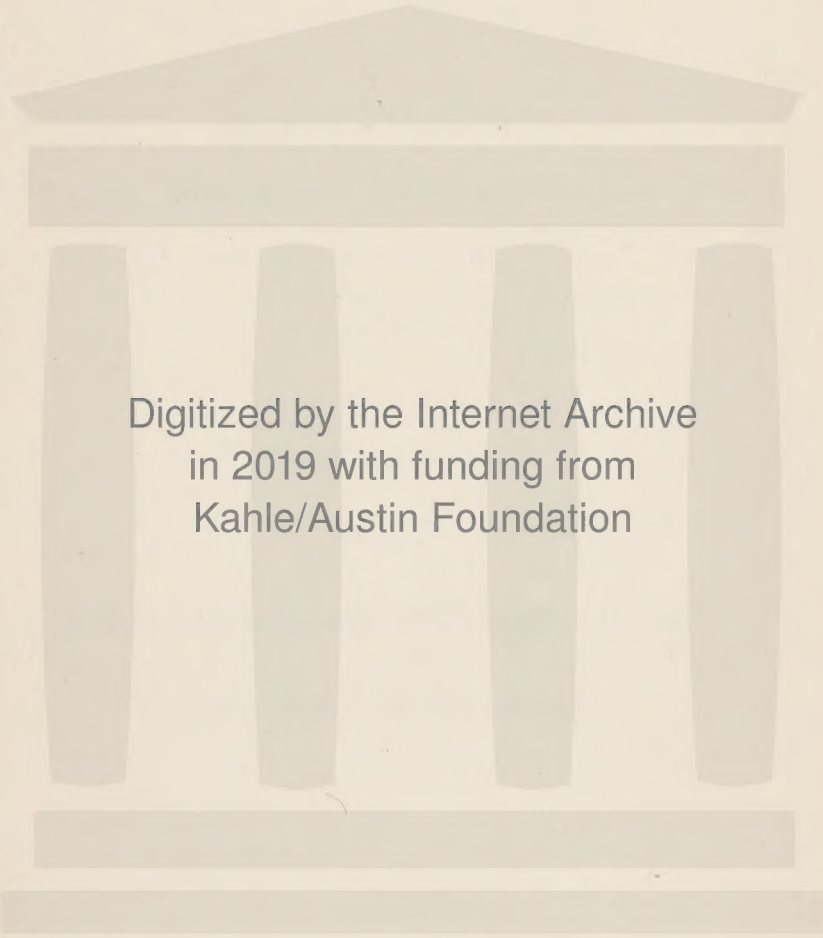
PROCEEDINGS

PART IV. IRON & STEEL

NUNC COGNOSCO EX PARTE



THOMAS J. BATA LIBRARY
TRENT UNIVERSITY



Digitized by the Internet Archive
in 2019 with funding from
Kahle/Austin Foundation

Second (*Triennial*)
Empire Mining and Metallurgical Congress

PROCEEDINGS

PART IV

METALLURGY OF IRON AND STEEL

(SECTION C OF CONGRESS)

*PROCEEDINGS OF THE SECOND (TRIENNIAL) EMPIRE MINING
AND METALLURGICAL CONGRESS, CANADA, 1927.*

Part I.—Report of Proceedings, Inaugural and other Addresses, and
General Papers.

Part II.—Mining.

Part III.—Petroleum.

Part IV.—Iron and Steel.

Part V.—Non-Ferrous Metallurgy.

The price of these Proceedings is \$10.00 for the whole of the five parts,
or any part may be obtained separately for \$3.00.

Second (*Triennial*)
Empire Mining and Metallurgical Congress
Held in Canada, August 22nd to September 28th, 1927.

PROCEEDINGS

Edited by

R. P. D. GRAHAM

PART IV

METALLURGY OF IRON AND STEEL

(SECTION C OF CONGRESS)

MONTREAL, CANADA:
PUBLISHED AT THE OFFICES OF THE CONGRESS
923 DRUMMOND BUILDING, MONTREAL.

1928

Second (*Triennial*)
 Empire Mining and Metallurgical Congress

Canada, August 22nd to September 28th, 1927

Convening Body

THE CANADIAN INSTITUTE OF MINING AND METALLURGY.

HONORARY PRESIDENT

RT. HON. SIR ROBERT S. HORNE, G.B.E., K.C., M.P.

President

HON. CHARLES STEWART, M.P., *Minister of Mines for Canada.*

Honorary Vice-Presidents

THE SECRETARY OF STATE FOR DOMINION AFFAIRS

THE SECRETARY OF STATE FOR INDIA

THE SECRETARY OF MINES FOR GREAT BRITAIN

The Prime Ministers of:

AUSTRALIA, CANADA, GREAT BRITAIN, NEW ZEALAND, NEWFOUNDLAND, SOUTH AFRICA

The Premiers and Ministers of Mines of:

ALBERTA, BRITISH COLUMBIA, MANITOBA, NEW BRUNSWICK, NOVA SCOTIA,
 ONTARIO, QUÉBEC, SASKATCHEWAN

Vice-Presidents

THE PRESIDENTS OF THE TEN CONSTITUENT INSTITUTIONS

CHARLES CAMSELL, LL.D., F.R.S.C., F.G.S.A., *Deputy Minister of Mines for Canada*

<i>Chairman of the Main Committee</i>	- - - - -	GEORGE C. RILEY
<i>Vice-Chairman of the Main Committee</i>	- - - - -	J. G. ROSS
<i>Chairman of the Finance Committee</i>	- - - - -	J. L. AGNEW
<i>Chairman of the Transportation Committee</i>	- - - - -	GUY TOMBS
<i>Chairman of the Reception Committee</i>	- - - - -	J. MACKINTOSH BELL
<i>Chairman of the Publications Committee</i>	- - - - -	W. H. COLLINS
<i>Honorary Treasurer</i>	- - - - -	SIR CHARLES GORDON
<i>Treasurer</i>	- - - - -	WINTHROP BRAINERD
<i>General Secretary</i>	- - - - -	G. C. MACKENZIE
<i>Associate Secretary</i>	- - - - -	R. O. WHEATLEY
<i>Editor</i>	- - - - -	R. P. D. GRAHAM

Canadian Main Committee

J. L. AGNEW	R. A. BRYCE	A. M. IRVINE	J. J. WARREN
C. A. BANKS	C. V. CORLESS	D. H. MACDOUGALL	F. R. WEEKES
J. P. BICKELL	J. A. DRESSER	LEWIS STOCKETT	
A. F. BRIGHAM	N. R. FISHER	R. C. WALLACE	

Second (*Triennial*) Empire Mining and Metallurgical Congress

PREFACE

The conditions under which the Second Congress was held were different in several notable respects from those of the First Congress, which met in London in June, 1924. That meeting, convened by institutions and associations representing the mineral and metal industries, the colliery proprietors, and the iron and steel manufacturers, in the United Kingdom, lasted only four days, and the sessions were all held at the British Empire Exhibition, Wembley. It was, of necessity, inaugural in character, and apart from the presentation of a series of noteworthy papers dealing with various phases of the mining and metallurgical industries of the Empire, it had as its chief business the drafting and adoption of a Constitution and Rules for an Empire Council of Mining and Metallurgical Institutions. The Constitution as adopted is as follows:

CONSTITUTION

The Council shall consist, until otherwise determined, of two representatives from each of the following Constituent Institutions:

- The Institution of Mining and Metallurgy
- The Institution of Mining Engineers
- The Institution of Petroleum Technologists
- The Canadian Institute of Mining and Metallurgy
- The Australasian Institute of Mining and Metallurgy
- The Chemical, Metallurgical and Mining Society of South Africa
- The South African Institution of Engineers
- The Mining and Geological Institute of India
- The Iron and Steel Institute
- The Institute of Metals

OBJECTS OF THE COUNCIL

To serve as an organ of intercommunication and co-operation between the Constituent Bodies and for the promotion and protection of their common interests.

FUNCTIONS OF THE COUNCIL

- (a) To foster and maintain throughout the Empire a high level of technical efficiency and professional status.
- (b) To convene successive Mining and Metallurgical Congresses within the Empire.

POWERS OF THE COUNCIL

The Council shall have power to initiate projects for consideration with a view to action and generally to direct the affairs committed to it by the Constituent Institutions, but it shall not commit them to any act or financial obligation without first obtaining the sanction of the respective Councils. Further, the Council shall not have any authority, implied or explicit, to interfere in the domestic affairs of any of the Constituent Institutions, whose complete autonomy shall remain intact.

Dr. R. C. Wallace, as President of the Canadian Institute of Mining and Metallurgy at that time, was one of the official delegates of the Canadian Institute attending the First Empire Congress in London, and on his return to Canada he submitted a proposal to the Institute Council that they should consider the feasibility of having the Second Congress meet in Canada. The proposal was received with enthusiasm, and a preliminary canvass of the situation having made it evident that the Institute might safely assume the responsibility of acting as convenor, an invitation was forwarded to the Empire Council to hold the Second Congress in Canada in 1927. This invitation was accepted by the Empire Council on behalf of the Constituent Institutions.

The Second Congress opened in Montreal on August 22nd, with addresses by the Honorary President, The Right Hon. Sir Robert S. Horne, *G.B.E., K.C., M.P.*, and the President, the Hon. Charles Stewart, *M.P.*, Minister of Mines for Canada. Technical sessions were held on this and the following day, the proceedings including the presentation of a notable paper by Sir Thomas H. Holland on a *Proposed Review of the Mineral Resources of the Empire*. The proposals outlined in this paper were warmly endorsed in addresses by official representatives from various parts of the Empire, and at the conclusion of the discussion the following resolution was adopted:

This Second (Triennial) Empire Mining and Metallurgical Congress, assembled in Canada, having discussed a proposal for instituting a review of the mineral resources and industries in each appropriate administrative unit throughout the Empire, and of the conditions affecting their development, embodied in a paper submitted under the auspices of The Institution of Mining and Metallurgy by Sir Thomas H. Holland,

RESOLVED, that the proposal be referred to the Empire Council of Mining and Metallurgical Institutions, to be transmitted to the Councils of the constituent bodies for consideration, with a request that they will formulate their views and communicate them to the Empire Council for further action.

On the following day, special trains conveyed the party to Ottawa, where members had the opportunity of meeting His Excellency the Viscount Willingdon, Governor General of Canada, and The Hon. Charles Stewart, representing the Prime Minister, at a luncheon tendered by the Congress.

Following this, two days were devoted to technical sessions in Toronto, and over the week-end there were excursions to Hamilton, Niagara Falls, and other points of interest.

From Toronto, the Congress trains proceeded to some of Ontario's world-famous mining districts, visits being paid in turn to nickel-copper mines at Sudbury, silver mines at Cobalt, and gold mines at Kirkland Lake and Porcupine.

After leaving the Porcupine area, the party divided, those who had elected to take Tour *A* going westward to the Pacific coast, while Tour *B* proceeded eastward across Quebec and the Maritime Provinces to Newfoundland. In each case the principal mining centres and metallurgical plants, as well as some hydro-electric plants, were visited, and a number of technical sessions were held: on Tour *A*, in Winnipeg, Vancouver, Jasper, and Quebec; and on Tour *B* in Quebec and St. John's, Newfoundland. Tour *A* covered approximately 7,750 miles, and Tour *B* 5,525 miles. The final session of the Congress was held in Quebec on September 26th. It is with considerable gratification that we are able to record that, from the opening day to the closing of the Congress, there was not a single case of illness nor an accident of any kind.

Official banquets were held in Montreal, Toronto, Winnipeg, Vancouver, and Jasper, and in St. John's, Newfoundland. At numerous other points the Congress parties were lavishly entertained by mining companies and individuals; and golf and other clubs in the various cities visited were most hospitable in extending facilities for recreation. The Congress is especially indebted to the Ladies' Committees, which, at each stopping place in the course of the tours, were indefatigable in providing entertainment for the visiting ladies.

Lists compiled from the official registers and other available sources show that the total attendance at the Congress was well over twelve hundred. Of these, 350 participated in

Tour *A* and 96 in Tour *B*. The gathering may be truly described as exceptionally well representative of every important phase of the mining and metallurgical industries in all parts of the Empire. The personnel included official delegates from each of the following institutions:

- The Institute of Metals (London)
- The Institution of Mining Engineers (London)
- The Institution of Mining and Metallurgy (London)
- The Iron and Steel Institute (London)
- The Institution of Petroleum Technologists (London)
- The Chemical, Metallurgical, and Mining Society of South Africa
- The South African Institution of Engineers
- The Rhodesia Chamber of Mines
- The Australasian Institute of Mining and Metallurgy
- The Mining and Geological Institute of India
- The Canadian Institute of Mining and Metallurgy

In addition, the Congress had the privilege of welcoming official delegates from the United States Bureau of Mines and the American Institute of Mining and Metallurgical Engineers.

A total of 42 papers were presented at the several technical sessions, and with the exception of three these were all printed as 'separates' in advance of the opening of the Congress and distributed to delegates before the meetings. In addition, a 270-page Official Programme was issued giving complete information regarding arrangements for the Congress, with itineraries of the excursions and brief descriptions of the various points of interest visited; and a series of 'short focus' papers was prepared, each giving in concise form particulars of operations at individual mines and metallurgical plants inspected during the tours. Besides these purely Congress publications, specially prepared booklets descriptive of the Dominion's mining and metallurgical industries were issued by the Federal Department of Mines, by the Ontario and Quebec departments of mines, and by several of the mining companies.

The papers submitted to the Congress dealt with a wide variety of topics relating to recent progress, and the present status and future prospects, of the mining and metallurgical industries in almost every section of the Empire where these industries are carried on. Many of the papers have been given wider publicity than was possible at the time of the

Congress by publication in the *Transactions* of the constituent institutions, and some also in technical journals. Following the procedure of the First Congress, the complete *Proceedings* are now issued in five Volumes, a full list of the Papers being printed in each volume.

The funds required for carrying out the extensive programme of the Congress were in the main contributed by the Dominion Government, by the governments of the several Provinces, by the Government of Newfoundland, by Canadian mining and smelting companies, and manufacturers of mining machinery, explosives, etc., and by the Canadian Pacific and the Canadian National railways. Generous donations were also received from co-operating Institutions in the United Kingdom, South Africa, Australasia, and India. In all, sixty-six contributions were received, totalling about \$110,000.

The Second Congress was exceedingly fortunate in having, as its Honorary President, the Right Hon. Sir Robert S. Horne, *G.B.E., K.C., M.P.*, who took a most active interest in the proceedings and participated in the Montreal meeting. Much of the success of the Congress was due also to the President, The Hon. Charles Stewart, Minister of Mines for Canada, who rendered great services, both personally and through the Department of Mines, technical officers of which were detailed to accompany each of the special trains, and were available at all times to give information regarding the Dominion's mineral resources and industries. The Congress also received whole-hearted support from the departments of mines of each of the Provinces of Canada, and from the Government of Newfoundland.

Mining companies throughout Canada, and also the two great transcontinental railway systems, the Canadian Pacific and the Canadian National, and the Temiskaming and Northern Ontario railway, took a very active interest in the work of the organization and showed a keen appreciation of its importance to the Empire. The Congress owes much to them for their invaluable co-operation, and also to the management of the various mines and plants visited for their unflinching readiness to do all in their power to make the tours both instructive and enjoyable.

Acknowledgment must also be made of the notable service rendered by the numerous individuals who composed the various committees responsible for the organization and carrying out of the Congress. The smoothness with which the entire Congress programme functioned is a splendid tribute to the efficient manner in which each of these committees carried out the particular duties assigned to it.

We desire further to record our thanks to the Empire Council of Mining and Metallurgical Institutions, and more especially to its joint general secretaries, Mr. Charles McDermid and Mr. George C. Lloyd, for much helpful advice both during the organization period and while the Congress was in progress. Thanks are also due to the Cunard Steamship Company for the excellent arrangements they made for the comfort of delegates who sailed from England to Canada in the official Congress boat, the *Alaunia*.

Although the Empire Council Banquet, held in London on November 22nd, was an aftermath, and not a part of the actual proceedings, of the Congress, it may be fittingly referred to here since a large proportion of those present had been with the Congress in Canada, and one of its objects was to review the results of the Congress. Notable speeches were delivered by Sir Thomas H. Holland, Chairman of the Empire Council, who presided, and by others prominently identified with the mining and metallurgical industries, as well as by representatives of the governments of various parts of the Empire.

GEO. C. MACKENZIE,
General Secretary.

R. O. WHEATLEY,
Associate Secretary.

923 DRUMMOND BUILDING,
MONTREAL,
April, 1928.

TABLE OF CONTENTS, PARTS I-V

PART I

(*General Section of Congress*)

REPORT OF PROCEEDINGS

Addresses at Inaugural Session, Montreal:

The Mineral Industries of the Empire: By the Hon. President, THE RIGHT HON. SIR ROBERT HORNE, *G.B.E., K.C., M.P.*

The Status of the Canadian Mineral Industry: By the President, THE HON. CHARLES STEWART, *Minister of Mines for Canada.*

Technical Sessions, Receptions, etc. at Montreal, Ottawa, Toronto, Niagara Falls, and Hamilton.

The Trans-Canada Tours A and B (including Newfoundland):

Itinerary, Technical Sessions, Receptions, etc.

Concluding General Session at Quebec.

PAPERS

'Proposed Review of the Mineral Resources of the Empire': By SIR THOMAS H. HOLLAND (President, The Institution of Mining and Metallurgy) and Other Authors.

Discussion.

Adoption of resolution.

'An Outline of Mining and Metallurgical Practice in Australasia': Vol. I, BY LEADING AUTHORITIES IN COLLABORATION.

(*Prepared by request of the Australasian Institute of Mining and Metallurgy*).

Vol. II, 'The Utilization of Brown Coal in Victoria': By H. HERMAN (Member, Aust. Inst. M. & M.)

'Base Metal and Base Mineral Resources of The Union of South Africa': By C. J. N. JOURDAN (Member, C.M. & M. Soc. S. Af.)

Discussion.

'The Development of Gold Mining in Canada': By GEO. E. COLE (Member, C. Inst. M. & M.)

Discussion.

'The Silver Mining Industry in Canada': By ARTHUR A. COLE (Member, C. Inst. M. & M.)

Discussion.

'Canadian Copper and its Production': By C. P. BROWNING (Member, C. Inst. M. & M.)

Discussion.

- 'Lead and Zinc in Canada': By T. W. BINGAY and F. J. ALCOCK (Members C. Inst. M. & M.)
Discussion.
- 'Portland Cement in Canada': By W. A. TOOHEY.
- 'Mineral Exploration in Newfoundland During the Past Decade':
By A. K. SNELGROVE (Student Member, C. Inst. M. & M.)
- 'The St. George's Coal Field, Newfoundland': By HERBERT A. BAKER.

PART II—MINING

(Section A of Congress)

- 'Mining Coal under the Sea in Nova Scotia': By F. W. GRAY (Member, C. Inst. M. & M.)
Discussion.
- 'The Coal Mining Industry of Western Canada': By R. STRACHAN, W. J. DICK, and R. J. LEE (Members, C. Inst. M. & M.)
Discussion.
- 'Coal Washing at the Linsi Mine, Kailan Mining Administration, North China': By ALEX. DOCQUIER, L. BATAILLE, and R. BEETLESTONE. (Communicated by W. S. NATHAN, Member, Inst. M. & M.)
- 'Progress in Research on Health and Safety in Coal Mining, 1924-27':
By J. S. HALDANE (Hon. Member, Inst. M.E.) and R. V. WHEELER (Member, Inst. M.E.)
- 'Asbestos Mining and Milling': By J. G. ROSS (Member, C. Inst. M. & M.)
- 'Dewatering the Lower Levels of the Simmer and Jack Mines, Limited':
By R. CRAIB (Member, S.Af. Inst. Eng.)
Discussion.
- 'The Tipping and Guiding of Vertical Skips': By G. W. SHARP (Member, S.Af. Inst. Eng.)
- 'Deep Level Mining and High Temperatures': By A. MAVROGORDATO and H. PIROW (Members, S.Af. Inst. Eng.)
Discussion.
- 'The Sinking and Equipment of the Ventilation Shaft of the Government Gold Mining Areas Mine': By A. JOB (Member, S.Af. Inst. Eng.)
Discussion.
- 'Improvements in Drilling Efficiency with Jack-Hammers': By P. M. NEWHALL and L. PRYCE (Members, S.Af. Inst. Eng.)
Discussion.
- 'A New Form of Air Meter and the Measurement of Compressed Air':
By E. J. LASCHINGER (Member, S.Af. Inst. Eng.)
Discussion.
- 'Methods of Eliminating Barren Rock from Ore at The Sub Nigel Mine, Transvaal': By W. A. QUINCE (Member, C. M. & M. Soc. S. Af.)
Discussion.
- 'Method of Mining at Wabana': By J. B. GILLIATT.

PART III—PETROLEUM

(Section B of Congress)

- 'Conditions affecting the Petroleum Prospects of the Empire':** By SIR THOMAS H. HOLLAND (Member, Inst. P.T.)
- 'Economics of the Petroleum Situation in British Dominions':** By SIR FREDERICK BLACK (Member, Inst. P.T.)
- 'Progress and Prospects of Oil Production':** By E. H. CUNNINGHAM-CRAIG (Member, Inst. P.T.)
- 'Petroleum Refining Facilities within the British Empire':** By JAMES MCCONNELL SANDERS (Member, Inst. P.T.)
- 'Petroleum and Natural Gas in the Dominion of Canada':** By R. B. HARKNESS, G. S. HUME, O. B. HOPKINS, S. C. ELLS, R. T. ELWORTHY, and S. J. COOK, with an introduction by JOHN NESS (Members, C. Inst. M. & M.)
Discussion.
- 'Possible Auxiliary Sources of Liquid Fuels':** By A. W. NASH (Member, Inst. P.T.)
Discussion.
-

PART IV—IRON AND STEEL

(Section C of Congress)

- 'Manganese, the Ores and the Metal; with an Account of the History and Production of Ferro-Manganese':** By SIR ROBERT A. HADFIELD, Bt. (Member, I. & S. Inst.)
- 'Low-Carbon Alloys of Iron and Manganese':** By SIR ROBERT A. HADFIELD, Bt. (Member, I. & S. Inst.)
- 'India's Resources in Raw Materials for a Domestic Iron and Steel Industry':** By CYRIL S. FOX (Member, M. & G. Inst. of India.)
- 'The Manufacture of Steel in India by the Duplex Process':** By B. YANESKE (Member, I. & S. Inst.)
- 'Magnesia Refractories for Steel Furnaces':** By G. M. CARRIE (Member, C. Inst. M. & M.) and C. F. PASCOE.
- 'The Cascade Method of Pouring Steel':** By J. G. MORROW (Member, C. Inst. M. & M.)
- 'The Impact Resistance of Steels at Low Temperatures':** By I. F. MORRISON and A. E. CAMERON (Member, C. Inst. M. & M.)
- 'Smelting Titaniferous Ores of Iron':** By A. STANSFIELD (Member, C. Inst. M. & M.)
Discussion.

PART V—NON-FERROUS METALLURGY

(Section D of Congress)

'Nickel—Past and Present': By ROBERT C. STANLEY (Member, Am. Inst. M. & M. E.)

'Precious Metals in the Sudbury Ores and their Recovery': By C. LANGER and C. JOHNSON (Members, Inst. of Metals.)
Discussion.

'Notes on the Operation of the Reduction Plant at West Springs, Limited': By CARL R. DAVIS, J. L. WILLEY, and S. E. T. EWING (Members, S. Af. Inst. Eng.)

'The Contact Process for the Manufacture of Sulphuric Acid from Zinc Blende Roaster Gases': By STANLEY ROBSON (Member, Inst. of Metals.)
Discussion.

PART IV—IRON AND STEEL

(Section C of Congress)

CONTENTS

	PAGE
<i>Preface</i>	v
<i>Table of Contents of Parts I-V</i>	xi
<i>Papers and Discussion</i>	
‘Manganese, the Ores and the Metal; with an account of the History and Production of Ferro-manganese’: By SIR ROBERT A. HADFIELD, Bt. (<i>Past-President, I. & S. Inst.</i>).....	1-92
‘Low-carbon Alloys of Iron and Manganese’: By SIR ROBERT A. HADFIELD, Bt. (<i>Past-President, I. & S. Inst.</i>).....	93-162
‘India’s Resources in Raw Materials for a Domestic Iron and Steel Industry’: By CYRIL S. FOX (<i>Member, M. & G. Inst. of India</i>).....	163-279
‘The Manufacture of Steel in India by the Duplex Process’: By B. YANESKE (<i>Member, I. & S. Inst.</i>).....	281-434
‘Magnesia Refractories for Steel Furnaces’: By G. M. CARRIE (<i>Member, C. Inst. M. & M.</i>) and C. F. PASCOE.....	435-521
‘The Cascade Method of Pouring Steel’: By J. G. MORROW (<i>Member, C. Inst. M. & M.</i>).....	522-532
‘The Impact Resistance of Steels at Low Temperatures’: By I. F. MORRISON and A. E. CAMERON (<i>Member, C. Inst. M. & M.</i>).....	533-551
‘Smelting Titaniferous Ores of Iron’: By ALFRED STANSFIELD (<i>Member, C. Inst. M. & M.</i>).....	552-568
Introductory Remarks and Discussion.....	568-578
<hr/>	
<i>Personal Index</i>	579-581
<i>General Index</i>	583-588

MANGANESE, THE ORES AND THE METAL; WITH
AN ACCOUNT OF THE HISTORY AND PRODUCTION OF FERRO-MANGANESE*

BY SIR ROBERT HADFIELD, BT.
(*Past-President, Iron & Steel Inst.*)

(Sydney, N. S., meeting, September 9th, 1927)

CONTENTS

(A) The Metal Manganese and its Properties

Section	Page
1. Introduction.....	3
2. Objects of the Paper.....	6
3. History.....	7
4. Ores of manganese.....	13
5. Distribution of manganese ores.....	14
6. Uses and applications of manganese ores.....	45
7. Pure manganese and its history.....	49
8. Production of metallic manganese:	
(a) Early processes.....	52
(b) Modern methods.....	54
9. Properties of metallic manganese:	
(a) Specific gravity.....	56
(b) Melting point.....	57
(c) Specific heat.....	57

(B) The Production of Ferro-Manganese and its History

10. The alloys of iron and manganese.....	58
11. History of ferro-manganese.....	60
12. Manufacture of ferro-manganese.....	84
13. Carbon-free ferro-manganese.....	90
14. Conclusion.....	91

*This paper was presented at the Annual Meeting of the Iron & Steel Institute, May 5th-6th, 1927.

LIST OF FIGURES

Figure	Page
1. General view of the Tchiaturi manganese ore basin (valley of the Kvirila river).....	15
2. View of series of horizontal tunnels of the famous Perevici mines	16
3. View of the Tchiaturi station and the manganese ore platform.	17
4. Outcrop of manganese ore, Insuta-Dagwin deposits, Gold Coast Colony, as discovered by the Geological Survey in 1914....	25
5. View of Insuta manganese mine, showing washing plant and benches in ore.....	26
6, 7 & 8 Views of Kandri and South Tirody mines, Central Provinces, India.....	30-31
9. Diagram of world's production of high-grade manganese ore...	38
10. Coloured map of the world, showing the sources of supply of manganese ores.....	40
11. Diagram showing heat content of manganese at various temperatures, in comparison with other metals.	56
12. Portrait of Mr. Alexandre Pourcel.....	85
13. View of works of The Darwen and Mostyn Iron Co., Ltd.....	88

LIST OF TABLES

I. World's production of high-grade manganese ore.....	38
II. Specific gravity of manganese according to different authorities.	56
I II. Analyses of British manganese alloys, including ferro-manganese of high and low carbon, together with spiegel, silico-spiegel, also metallic manganese.....	59
IV. Specimens of ferro-manganese exhibited by Terre Noire Works in 1878.....	73
V. List of British makers of ferro-manganese, with the numbers of furnaces and their capacity per annum.....	89
VI. Analyses of ferro-manganese (80 per cent manganese) in various grades.....	89-90

(A)—THE METAL MANGANESE AND ITS PROPERTIES

SECTION 1.—INTRODUCTION

The object of the following introduction or foreword to the author's paper now presented is to make clear to the reader the great interest which during May and June of this year has been aroused, both in Great Britain and the United States, on this important subject of Manganese and its Ores.

Despite the great mineral wealth of Canada in gold, silver, copper, nickel, and iron, and the occurrence of notable deposits of other valuable metalliferous minerals, as far as the author is aware no manganese ore deposits of any very considerable importance have hitherto been encountered either in the Dominion itself or in the adjacent Colony of Newfoundland. Manganese oxides are largely used in the electrical and other industries, but the main importance of the metal itself is derived from the fact that it is indispensable in the manufacture of steel. Canada is therefore under the necessity of relying, for her essential supplies of manganese ores, almost entirely upon imports from abroad, a position she shares with Great Britain itself and with the United States of America, as well as with the great iron and steel producing countries of the European Continent. Whilst, happily, within the Empire itself, and in other parts of the world, are to be found abundant supplies of manganese ore, yet these are, for the most part, situated in regions remote from the great iron and steel manufacturing centres which have, therefore, to depend, for the continuity of their supplies, upon ores derived from countries far removed from them.

The situation is one of no little importance, and in one sense serious, but it is now receiving widespread recognition and attention. Thus, in addition to the present paper which the author has the honour of presenting at this Congress, an exceedingly important paper has been read by Sir Thomas Holland entitled "Proposed Review of the Mineral Resources of the Empire", which, among many other issues, has caused renewed attention to the necessity of securing adequate supplies of manganese ores. The main points dealt with by Sir Thomas Holland were:

Mineral Deficiencies of the Central Powers during the War, and the
 Lesson to be Learned;
 The Meaning of Current Production Figures;
 Effect of a Rising Output;
 Financial Effect of Declining Totals;
 The Leith Committee;
 Fixed Distribution of Mineral Deposits;
 Smelting and Refining Facilities;
 Mineral Laws;
 State Ownership of Minerals;
 Summary and Conclusions.

At the Spring Meeting of the Iron and Steel Institute this year, the great importance of this subject was evinced in two papers read by the author entitled (1) "The Metal Manganese and its Properties: also the Production of Ferro-Manganese and its History", and (2) "Alloys of Iron and Manganese containing Low Carbon". The author has been at work on these papers for many months and has endeavoured to deal very fully with the special questions to which they relate.

The various papers referred to have appeared at what may be regarded as a propitious moment as, prompted by the very serious nature of the problems involved, our American cousins were, at the end of April last, discussing the same subject. At the Cleveland (Ohio) Meeting of the American Institute of Mining and Metallurgical Engineers no less than six papers on Manganese were down for reading. The question of the supply of manganese ores has, similarly, been considered to be of such a vital nature that the U.S. Government was represented by several of its most prominent officials, amongst those present at the meeting referred to having been the Secretary for War, Mr. Dwight F. Davis.

Discussions of an extremely interesting nature took place both on the occasion of the reading of the author's papers at the meeting of the Iron and Steel Institute, and at a meeting of the Institution of Mining and Metallurgy, held in London a few weeks earlier. At that meeting papers bearing on mineral resources, and on mining law, were read by Sir Thomas Holland, Sir Richard Redmayne and Mr. Gilbert Stone, respectively, and the author was invited to open the ensuing discussion. He has ventured to include in the present paper

the gist of the remarks he made on that occasion, as they appear to be germane to the subject under present consideration.

This 'Manganese' question is really one of similar character to the 'Rubber' one. It may be mentioned that the papers presented at the Cleveland (O.) Meeting comprised about 120 pages, the following being the titles with a short abstract and some comments on their contents. Chief of these papers is that by a recent President of the American Institute of Mining and Metallurgical Engineers, Mr. John V. W. Reynders, of New York, entitled "Manganese Resources in Relation to Domestic Consumption". The paper contains valuable information on the sources of production in various countries, including Russia, India, Gold Coast, Brazil, and elsewhere; a general résumé of the resources, in which is given a table showing the manganese alloys and ore produced in the United States and imported from principal foreign sources from 1917 to 1925; the position of the United States; the bearing of the tariff on reserves in the U.S. of domestic ore. This paper pleads that the existing American tariffs on manganese should be repealed. It is pointed out that in 1926, on the basis of the import duties imposed, nearly \$8,000,000 was paid to the United States Customs by the American consumers of manganese in order that the domestic production might be 22,400 tons; thus, in order to make possible the domestic production of 22,400 tons of manganese ore having a sales value of \$31 per ton, duty included, the public at large was taxed to the extent of \$360 per ton, an outlay of \$10 to produce \$1. It is further stated: "It is obvious that the existing tariff on manganese should be repealed. It fosters no industry and depletes our too scanty reserves of this essential raw material. A burden of \$8,000,000 placed upon the nation's industry in order to force the production of manganese ore to the extent of only \$600,000 requires no argument to demonstrate its absurdity". Mr. Reynders pointed out that the American Sub-Committee on Manganese had suggested that the necessary appropriation should be made by the U.S. Government to provide for purchase in the open market, in equal yearly quantities over

a period of from six to nine years, of a total quantity of no less than 600,000 tons of ferro ores suitable for making ferro-manganese, equal in grade to the accepted foreign standards, this to be held in stock at a suitable location for tiding over war emergency.

Next, the paper by Professor Boylston, Professor of Metallurgy at the Case School of Applied Science, Cleveland (O.), on "The Importance of Manganese in the Steel Industry". In this paper Professor Boylston says: "It was in 1888 that Robert Hadfield published at some length his account of the effect of manganese as an alloying element in steel, and described the unique properties of the now famous Hadfield manganese steel containing about 12 to 14 per cent manganese and 1.25 per cent carbon." The subject of "Manganese in Non-Ferrous Alloys" is ably dealt with by Mr. M. G. Corsor, of New York.

Then followed a valuable paper on the "Geology of the Manganese Ore Deposits of the Gold Coast, Africa", by an Englishman, Sir Albert E. Kitson, Director of the Geological Survey, Gold Coast. This paper dealt with the nature of the manganese ore deposits of the Gold Coast, already a valuable source of supply of manganese ore. Two important papers were presented on "Reserves of Lake Superior Manganiferous Iron Ores", by Carl Kapffe, Manager, Iron Ore Properties, Northern Pacific Railway Company, and "Minnesota Manganiferous Iron Ores in Relation to the Iron and Steel Industry", by T. L. Joseph, E. P. Barrett, and C. E. Wood, all of which authors are connected with the U.S. Bureau of Mines. These two papers deal with the phase of the subject relating to low-grade manganese iron ores which, whilst plentiful enough in America, do not solve the question of how to obtain ores rich enough in manganese from which to produce the material ferro-manganese, of such vital interest, in fact an absolute necessity, for the modern steel-maker.

SECTION 2.—OBJECTS OF THE PAPER

In view of the importance of manganese to the steel industry, the author thought it desirable to give some account of the metal, also of its production in ferro-alloy forms. Whilst

literature on the subject has appeared from time to time, it is in a somewhat disseminated form, and not readily available to the members of this Institute. The present paper endeavours, therefore, to give a general historical account of the metal manganese and the uses to which it has been applied. Naturally this is more specially concerned with its use in the steel industry — by far the largest industrial application — including the manufacture of modern alloy steels and also manganese steel, of which it forms a considerable proportion.

Another object of this paper is to show the interesting way in which the production and use of ferro-manganese was brought about, and the important part played in its development by our country. History shows the sequence to have been Heath in 1839, followed much later by Mushet, Prieger, Henderson, Bessemer, and finally our Honorary Vice-President, Mr. Pourcel, happily still with us. It is shown how the Henderson process was encouraged by Bessemer, then utilized in France, and resulted in the production of ferro-manganese of 60 to 80 per cent in the blast-furnace by Mr. Pourcel, to whom in this respect our chief debt is due.

In addition, there is given some account of the present world position as regards the resources of manganese ores, more particularly from the British point of view.

The properties of the metal manganese itself — a matter of some importance if we are fully to understand its effects on steel — are also referred to so far as they have been ascertained. In this respect our knowledge is still inadequate, though continued efforts are being made to remedy this deficiency.

SECTION 3.—HISTORY

Since the author's papers ⁽¹⁾ were read before the Institution of Civil Engineers in 1888, the literature regarding manganese has grown considerably. The history of the metal was briefly dealt with in those papers and in the Appendix by which they were accompanied.

⁽¹⁾ "Manganese in its Applications to Metallurgy. Some Newly Discovered Properties of Alloys of Iron and Manganese," *Proceedings of the Institution of Civil Engineers*, 1887-88, vol. xciii. pp. 1-126.

Naturally much more information has since come to light, and it may be as well to point out that Karl Wilhelm Scheele, to whom it is customary to ascribe the recognition of the existence of manganese, published his historical work, “*De Magnesia Nigra*,” in 1774. But Scheele had, as far back as 1740, been anticipated by Johann Theodor Pott, a pupil of Stahl, who first showed that the black oxide of manganese contained a principle differing from iron, with which this and other manganese oxides had previously been identified. However, Pott, whilst in this way removing a misconception, and so no doubt stimulating inquiry as to the true nature of this oxide, did not suggest that it contained a new metal. Bergman, on the other hand, came to the conclusion that perhaps the manganese was the calk, as he termed it, of a new metal. The principle itself was actually isolated in the year 1774 by Scheele’s pupil, Johann Gottlieb Gahn, and the discovery was announced in 1775. Gahn, who like Scheele was a Swede, is, moreover, credited with having invented the word *manganese* to describe the new substance, deriving it, it is said, by metathesis, from the word ‘magnesium,’ which he had, in the first instance, conferred upon it (¹). This was done to distinguish it from the radicle of *Magnesia alba*, the existence of which, although not established until Davy isolated the metal magnesium in 1808, was already suspected. Davy himself called his new metal *Magnium*.

For several centuries, indeed, the utmost confusion appears to have reigned in regard to the use of the word *magnesia*, which was applied indiscriminately to at least three totally dissimilar substances: the black oxide of manganese; magnetic — and possibly other — iron oxides; and magnesia itself, either in the form of the white oxide or the carbonate. Sometimes these substances were distinguished from one another by the use of qualifying terms, such as *nigra*, *ferrea*, and *alba*, respectively. This is exemplified in an early fourteenth-century MS. in the Sloane Collection, in the British Museum (No. 1754,

(¹) Other authorities ascribe both the discovery and the application of the name of the new principle to Bergman. On the other hand, M. le Comte Denis credits Guyton de Morveau, who endeavoured to reform the nomenclature of his day, with the invention, in 1785, of the word ‘manganese.’

fol. 6), which refers specifically to *magnesia ferrea*, “une pyere ke est ayment si tret fer.” At other times, as in MS. No. 3661 (fol. 135) of the same collection, which is a copy of an earlier MS. dating back to A.D. 1372, the term *magnesia* is used by itself, although the context shows that manganese oxide is meant, as the ingredient in question is for the purpose of making violet-glass, a use to which pyrolusite has, since time immemorial, been applied, and for which magnesia, as we know it, would be quite useless. The word *manganensis* often occurs, however, in the works of Albertus Magnus (1193-1280), while, according to Erwin Kuh ⁽¹⁾, the word *manganesium*, which had passed into current literature, was, at the suggestion of Buttmann, at the beginning of the nineteenth century shortened to *mangan*, and in that form has been adopted by German technical writers ever since to designate the metal.

The origin of the word has taxed the ingenuity of many writers. It has been variously ascribed to Magnesia, the name of cities in Thessaly and in Asia Minor; to Mangana in the East Indies; to *magnus*, a synonym, according to Webster (“Metallographia,” 1672), for iron; to *magnes*, the loadstone; and to μάγανον, a Greek word meaning “delusion,” or “mystification,” and rendered in “Larousse’s Grand Dictionnaire,” by Delâtre, as *manganon*. The latter, even if etymologically indefensible, may, in the circumstances at least, be regarded as appropriate! In Delâtre’s opinion, this title was conferred because the metal was found to be brittle, unstable, and readily oxidised.

As with the metal, so with its alloys, and especially manganese steel, which has the peculiar qualities of being hard when it should be soft; tough when it should be brittle; brittle when it should be tough; non-magnetic when it should be magnetic — that is, seeing there is no less than 88 to 90 per cent of iron in its composition; magnetic when it should be non-magnetic — that is, after heat treatment at about 600°C.; and possessing the combination of exceedingly high tenacity of 60 to 70 tons per square inch and elongation of no less than 50 to 60 per cent on a length of 8 inches. No other ferrous alloy has yet been discovered which shows such an extraordinary combination of these qualities.

(1) “Die Darstellung des chemischreinen Mangans.” Zurich, 1911.

Great interest was aroused at the time by the author's original papers just referred to. A similar paper was read by the author before the Iron and Steel Institute ⁽¹⁾ in 1888, and before the American Institute of Mining and Metallurgy ⁽²⁾ in 1893.

In the author's recently published book entitled "Metallurgy and its Influence on Modern Progress," the development of discoveries and inventions is fully examined. It is there shown how some of our important modern developments and inventions have been brought to full fruition and perfection, and that to accomplish this nearly always requires the work of not one but of many minds spread over a long period. This is well illustrated in the case of the development of the metal manganese, regarding which it will be interesting to mention the many names constituting the chain of workers who have played the principal part from its discovery up to its practical application and use. Amongst others was the Hon. Robert Boyle (1627-1691), one of the great early philosophers and chemists, who studied some of these metals, including manganese, in chemical combinations; also Glauber and Haig.

Boyle, whose services to science were unique, and who was generally and deservedly known as "the Father of Modern Chemistry," appears to have been interested in ores of manganese as far as they were then known. Boyle is even said to have discovered a mine of manganese ore in England. The following passage taken from Birch's "Boyle" (vol. i.) is probably the authority for this statement. He says: "I remember that having occasion in the country to pass by the work-house of an ingenious potter that I sometimes employed in his profession, and having viewed the ground somewhat attentively, among some other uncommon fossils that I took notice of, I made the discovery of manganese or magnesia, whereof I gave the potter an advertisement, which he afterwards thankfully made use of, having found the method very proper for the glazing and colouring of his vessels. However, there are in England, as well as in divers other countries, useful fossils that are wont

⁽¹⁾ *Journal of the Iron and Steel Institute*, 1888, No. II, pp. 41-82.

⁽²⁾ *Transactions of the American Institute of Mining and Metallurgy*, 1893.

to be overlooked by the unskilful." He also adds with regard to the ores, "And these are not only fictitious, but divers of them natural; such as manganese, by some called magnesia."

Professor J. H. Pepper, in his "Playbook of Metals" (New Edition, 1869), Chapter XXIII., headed "Manganese," stated: "This metal, after evading the processes of Boyle, Glauber, Haig, Pott, Kaim, Bergman, and Scheele, at last rewarded the persevering efforts of chemists by appearing at the summons of Dr. Gahn, who by mixing some black oxide of manganese with oil in balls, and placing them in a 'crucée brasque,' or crucible lined with charcoal, and then applying a most intense and vigorous heat, was rewarded with a button, or rather a number of small metallic globules, equal in weight to one-third of the mineral used." Pepper went on to say that naturally the charcoal had removed the oxygen, and the manganese remained in the metallic state. In order further to purify the button of manganese, it was necessary for the product thus obtained to be fused again with some pure carbonate of manganese and borax. He stated that the metal thus prepared had a specific gravity of 7.05 and presented a grey colour; it was hard and brittle, readily oxidised when exposed to the air in the moist state, and decomposed water at the boiling point, but very slightly, if at all, at ordinary temperatures.

It is believed that the metal must have been used even so far back as 2,000 years ago. Pepper in his book previously mentioned stated: "Manganese is now employed in the manufacture of the best crystal or flint glass, on which it is said to confer a greater brilliancy in consequence of the delicate amethystine colour it imparts to this siliceous mixture. Moreover, it does to all intents and purposes bleach the glass whilst the materials are in a state of liquefaction and incorporation, by giving oxygen to any carbon or protoxide of iron that may be present and discolour the pot of glass; hence it is called 'Glass Maker's Soap': the oxygen it contains burns away the carbon, and at the same time converts the protoxide of iron into peroxide, which is colourless when united with silicic acid."

The famous physician of his time, Sir Thomas Browne (1686), stated that "in making glass it had been ancient practice to cast in pieces of magnesite, or perhaps manganese."

As far as the author has been able to trace, nothing of practical importance as regards its employment in the manufacture of steel happened until Heath, about the year 1839, introduced the use of carburet of manganese into the manufacture of crucible steel. Heath in his patent declared that his invention consisted in the use of 'carburet of manganese' in any process whereby iron is converted into cast steel. Had he seen in his own day the Bessemer process in operation, he could not have said more; he well knew the effect produced by manganese on steel, and therefore claimed its employment in any process whereby iron is converted into cast steel. David Mushet went so far as producing what to-day would be called a species of ferro-manganese. His son, Robert Mushet, made practical use of spiegeleisen as applied to the Bessemer process; Prieger of Prussia did useful work, and Bessemer himself took a most active interest in encouraging the production of this metal by Henderson, in the form of ferro-manganese; and finally Pourcel, in France, solved the problem by producing, on an industrial scale, the valuable alloy now known as ferro-manganese, of which the world at present uses between 500,000 and 800,000 tons annually.

The above-mentioned figures have been arrived at in the following manner, and must necessarily be regarded as approximate only:

	Tons.
(1) The steel output of the world for 1925 was.....	87,000,000
(2) Assuming the manganese percentage averages 0.75 per cent, this output of steel requires a tonnage of manganese amounting to.....	625,000
(3) If ferro-manganese containing 80 per cent is used, this steel output requires a tonnage of ferro-manganese amounting to	780,000
If 0.75 per cent manganese is considered too high a percentage, then—	
(4) Assuming 0.50 per cent, the world output of steel requires a tonnage of manganese amounting to.....	400,000
(5) On the assumption of 0.50 per cent of manganese in the steel, the tonnage of 80 per cent ferro-manganese required would amount to about.....	500,000

As far as can be ascertained, the names of those chiefly concerned in this development, which has been of such immense importance and value to the world, are as follows:

Boyle	(1627-1691)	English	Robert Mushet	(1811-1891)	English
Pott	()		Prieger	()	German
Scheele	(1742-1786)	Swedish	Bessemer	(1813-1898)	English
Gahn	(1745-1818)	Swedish	Henderson	()	English
David Mushet	(1772-1847)	English	Pourcel	(1841-)	French

It will be seen that between the discovery of manganese and the complete development of its use over a century passed, and that to no one individual can the sole credit be given. Modern metallurgical developments naturally have proceeded much more rapidly, the environment being more suitable — in fact, the rate at which they now crowd fast one after the other is most remarkable, and, indeed, a sign of the times.

SECTION 4.—ORES OF MANGANESE

The affinity of manganese for oxygen is very great, and the metal is, consequently, nowhere found in the free or uncombined state. Its ores, of which, metallurgically, the oxides are the most important, are very widely distributed. They are even found, in the form of nodules, thickly strewn over the ocean beds for hundreds of miles and often at great depths, as well as at the bottoms of many lakes. Manganese ores are invariably associated with iron ores. At the same time, as mentioned later, iron is not found in any important quantity with the commercially workable deposits of manganese, which also are confined to comparatively few countries. The commonest varieties are psilomelane and pyrolusite. This latter is the 'black oxide of manganese,' a dioxide containing, when pure, 63.2 per cent manganese. The richest oxide (MnO), containing 77.5 per cent manganese, occurs as the mineral manganosite. The great bulk of the manganese ores employed commercially come from Southern and Central India, from the Gold Coast, and from Georgia and Brazil. The invariable association of iron with manganese complicates the commercial classification of manganese ores, which range in quality from the richest in manganese, containing the smallest percentages of iron, to the lowest grade ores, which are virtually iron ores

with not less than 5 per cent manganese. The most convenient classification is that proposed by Fermor, although, unfortunately, it has not been generally adopted. It is as follows:

	Manganese Per cent.	Iron Per cent.
Manganese ores.....	40 to 63	0 to 10
Ferruginous manganese ores.....	25 “ 50	10 “ 30
Manganiferous iron ores.....	5 “ 30	30 “ 56
Iron ores.....	0 “ 5	45 “ 70

SECTION 5.—DISTRIBUTION OF MANGANESE ORES

In the United Kingdom manganese ores occur in North Wales, Cornwall, Devonshire, Derbyshire, Worcestershire, and Cumberland. During the earlier part of the present century the annual output was in some years nearly 23,000 tons. Production has, however, fallen off very considerably, although, during the scarcity of supplies in the Great War, it rose again, and in 1918 attained 17,465 tons. In 1924 the world consumption of manganese ores was 1,450,000 tons, that of the United Kingdom alone having amounted to 331,527 tons, from which it is obvious that the home supply is quite insignificant; hence the importance of securing an adequate source of supply to our country. It should, however, be noted that the figures relating to manganese ore production and consumption vary considerably, according to the various authorities, and it is by no means always clear what grades are included or excluded in the official statistics published from time to time. The information available up to the time of the preparation of this paper is embodied in Table I (page 38).

An important monograph ⁽¹⁾ on manganese ore, by Mr. Datico Zereteli, was published in 1925, from which the following particulars are quoted. It is satisfactory to note that, even if the manganese resources of the United Kingdom are on so small a scale, the resources of the Empire rank above those of any other country. Thus while, in 1924, Brazil pro-

⁽¹⁾ “Manganese Ore, with Special Reference to Georgian Ore.” Dryden Press. London, 1925.



Figure 1.—General view of Tchiaturi manganese ore basin
(Valley of Kvirila river).

duced 200,000 tons, and Georgia in Russia, which before the war was the principal producer, contributed 480,795 tons, India produced no less than 639,210 tons, and the Gold Coast 255,647 tons. Manganese ores are also found in other parts of the British Empire, such as South Africa, East Africa, Canada, and Australia.

The chief European supplies are derived from the Georgian deposits, of which those of Tchiaturi are the most extensive, being estimated, according to Zereteli, to contain nearly 220,000,000 tons, 73,000,000 having already been extracted. Further very extensive deposits occur in other parts of the Union of Socialist Soviet Republics, notably in the Nikopol and Gaisinsk districts, in the Urals, in Siberia, and in North Caucasica. Small amounts of rich (60 per cent manganese) ores are found in Spain, Italy, and Sweden, and lower grade ores are found in France, Belgium, Germany, Greece, and Turkey.



Figure 2.—View showing series of horizontal tunnels of the famous Perevici mines.

By the kindness of the publishers, Messrs. J. Davy & Sons, Ltd., of the Dryden Press, the author is able to give several of the illustrations which appear in the monograph by Mr. Zereteli on the manganese ores produced in Georgia. Figure 1 shows a general view of the Tchiaturi manganese ore basin (valley of the Kvirila river); Figure 2 shows a series of horizontal tunnels of the famous Perevici mines; and Figure 3 is a view of the Tchiaturi station and the manganese ore platform. Mr. Zereteli presents much other valuable information, including the average monthly prices of the cheaper grades of ore, as well as ferro-manganese, from 1914 onwards. In addition to the figures given by Mr. Zereteli, copious statistics relating to manganese ores have been published elsewhere.

Reference was made at the beginning of this paper to the inconsiderable importance of such manganese ore deposits as have hitherto been encountered in Canada. Pyrolusite containing from 85 to 90 per cent manganese dioxide has



Figure 3.—Tchiaturi station and the manganese ore platform.

been found in Nova Scotia and in New Brunswick (T. Crook: *Economic Minerals*; London, 1921, p. 219), and some forty years ago the annual production of manganese ores from the Maritime Provinces averaged over 1,500 tons (Graham: *Mines and Mineral Deposits of Canada*; Proceedings of Empire Min. & Met. Congress, London, 1924, p. 115). Very low grade manganiferous ores, containing less than 10 per cent Mn, occur in south Alberta and small deposits of high-grade ore (50 per cent Mn) have been worked at Kaslo, on Kootenay lake, some 600 tons having been derived from these deposits in 1919 (Penzer: *Non-Ferrous Metals*; London, 1924, p. 158). The low-grade (15 per cent) ores of Walton, Hants county, Nova Scotia, can be concentrated to a 45 per cent manganese product (*Mineral Industry of the British Empire "War Period"*, p. 41, 1921).

During the War, Canadian consumption of ferro-manganese amounted to about 1,000 tons per month, all of which had to be imported from the United Kingdom, or

from the United States, at prices ranging from \$200 to \$300 per ton (*ibid*, p. 42). Whereas, in 1925, Canada exported 13,338 tons of ferro-manganese and other ferrous alloys, the production of manganese ore in 1924, the last year for which the completed figures are available, amounted only to 530 tons (*Manganese and Manganiferous Ores and Deposits in 1924*, Bureau of Mines, Washington, 1926), while her imports of ore, described in the Mineral Industry of the British Empire, 1926, (p. 178) as "manganese oxide", amounted to no less than 51,183 tons.

In Newfoundland, large deposits of low-grade manganese ores occur on the northeast coast, along the shores of Conception bay and at other places in the same locality, as well as Trinity bay and Placentia bay (Non-Ferrous Metals, p. 162). A manganite from Conception bay, analysed at the Imperial Institute, was found to contain 38 per cent manganese, 17.56 per cent silicon, 2.00 per cent iron, and 0.10 per cent phosphorus. A complex manganiferous carbonate of low grade has been located at Manuels brook.

Although high-grade ores occur in the United States, most of the manganese ore deposits in that country are low grade, or consist of manganiferous iron ore only. During the war, however, these native resources were extensively exploited, production in 1918 having attained to no less than 305,869 tons. In that year the production of ferruginous manganese ore (10 to 35 per cent manganese) and of manganiferous iron ore (5 to 10 per cent manganese) rose to 916,163 and 254,299 tons respectively, the production of ferro-manganese in the United States in that year reaching 333,027 tons. The known reserves are, however, small, and the output has fallen greatly; Montana, which in 1918 produced 199,932 tons, produced only 21,916 tons in 1924.

The North Central Experimental Station of the Bureau of Mines, Minneapolis, has collected information on the resources of manganiferous iron ore on the Cuyuna Range in Northern Minnesota. This information, based on drilling records and compiled by the Minnesota School of Mines, indicates that there are about $3\frac{1}{2}$ million tons of black ore containing low phosphoric acid with high silica, and about 24 million tons of

brown ore containing high phosphoric acid with low silica. It is believed that further examination will add to the figures just mentioned. The deposits are, however, of no great magnitude, and in no way relieve the United States of anxiety with regard to her future supplies.

As regards the production of high-grade manganese ore in the United States in 1925, the State of Montana produced considerably more high-grade manganese ore than all the other States combined. The Butte district furnished 47,500 tons of rhodochrosite, which were utilised mainly in the manufacture of ferro-manganese; shipments from this district are, however, somewhat irregular, and occur only when a considerable tonnage has been accumulated through the mining of zinc ore.

Incidentally and in comparison, it may be mentioned that the total iron ore mined in the United States in 1925 amounted to approximately 62 million tons, of an estimated value of £32,000,000. Out of this total, 37 million tons came from Minnesota and 15 million tons from Michigan. The steel produced from this ore and other materials amounted to somewhat over 45 million tons, and assuming that it contained an average of 0.75 per cent manganese, the total quantity of manganese ore required, allowing for 20 per cent loss in smelting, would be over 850,000 tons, whereas the United States itself in 1925 mined only 76,000 tons of high-grade manganese ore and 267,000 tons of low-grade manganese ore.

It must not be forgotten that although the U.S.A. has increased its steel production from about 31 million tons in 1913 to over 45 million tons in 1925, the production of steel outside that country is lower today than in 1913. The production of the main countries in Europe, including the United Kingdom, Germany, Luxemburg, France, Belgium, and Russia, was 38 million tons in 1913, whereas in 1925 this had dropped to 33 million tons. The chief loss is due to the falling off of about 3 million tons as regards Germany; France shows an increase of about 3 million tons. At any rate as regards Europe, at the present time there is really less demand for manganese ores than before the Great War.

Mr. P. M. Tyler ⁽¹⁾ has shown that for a probable average steel output in the world of 100 million tons annually for the next few years, about 750,000 tons of ferro-manganese per annum will be required, allowing, say, 16 to 18 lb. of 80 per cent ferro-manganese per ton of steel produced (or about 0.60 per cent manganese in the final product).

Making the necessary allowance for metallurgical losses, which may be reduced by improved electric processes, the production of this amount of ferro-manganese would require about 1,600,000 tons of 50 per cent ore, with an additional requirement of about 150,000 tons for all other purposes. These calculations are apparently based on a 25 per cent loss in smelting the ore. The pre-war production was about 2,200,000 tons of manganese ore, of which Russia supplied 1,200,000 tons, the remainder coming chiefly from India and Brazil.

As is well known, an exclusive contract was entered into in 1925 between the Union of Soviets and the American Harri-man interests. Mr. Tyler states that the essence of this contract is that, in return for installing modern equipment for economically mining, washing, and transporting the ore, the American company is conceded a monopoly of production of ore for export from the Tchiaturi Western Georgia district. The contract, which calls for a minimum exportation of 16 million tons in twenty years, is expected virtually to ensure that exports shall soon equal the pre-war rate. The lessees are obliged to install within five years facilities for shipping 2,000,000 tons annually, or substantially more than the total probable consumption of the world.

The minimum yearly export on which royalty has to be paid is 800,000 tons. If the quantity exported in any one year falls below 500,000 tons the concession is in danger of being cancelled; otherwise it stands for twenty years, after which time all the mines, together with railways, port, and other improvements connected with the undertaking, become the property of the Soviet Government.

(1) *Iron Age*, Aug. 29th, 1926.

The reserves in this district are now estimated to be about 250 million tons (about 30 million more than stated by Zereteli, see p. 15). The ores are easily mined, the annual output per employee in 1923, under Soviet management, being about 217 tons. It is stated that the present operators are under obligation to pay royalties, amounting to \$3 per ton for metallurgical ore and \$8 per ton for chemical ore (peroxide), for the first three years, rising afterwards to \$4 and \$9 per ton respectively. This \$4 rate means a fixed charge of at least 8 cents per unit, and in addition to this the Soviet Government is to receive a share in profits when the price of the ore exceeds a specified minimum.

The Russian Information Bureau has since stated that the production of manganese ore in the Soviet Union doubled during the Soviet fiscal year ended September 30th, 1926. Thus the production was about 25 per cent greater than that of 1913.

It is interesting to note that during the first year of operation by the Harriman Georgian Manganese Company, the output of the Tchiaturi fields, in Soviet Georgia, was 772,000 metric tons as compared with 436,000 tons in the previous year, 1924-25, an increase of over 80 per cent. The increase in the Nikopol fields, operated by a Soviet trust, was even greater, the production being 815,000 tons as compared with 380,000 tons in 1924-25, an increase of 114 per cent. The exports from Tchiaturi were 472,000 tons, and from Nikopol 235,000 tons. It is estimated that about half of the Tchiaturi exports were shipped to the United States.

Mr. John V. W. Reynders ⁽¹⁾, a leading consulting engineer of New York, describes the deposits in western Georgia very fully. At Tchiaturi, in the district of Sharopan, they lie practically horizontally at an elevation of 600 feet above the valley, with an average thickness of about 6 feet.

Transportation of the ore there largely takes place by means of two-wheeled ox-carts, travelling at the rate of under two miles per hour, handling one ton of ore in wicker-basket bodies. This is from the mines to the narrow gauge railway,

⁽¹⁾ *Transactions of the American Institute of Mining and Metallurgical Engineers*, Sept. 1926.

on which the ore is carried in narrow gauge trucks to Sharopan, a distance of about 28 miles, where a further transfer is effected to broad gauge car transport by main line to the seaport of Poti.

Mr. Reynders gives an interesting description of the labour conditions controlled by the Unions under the Soviet Government. So-called collective agreements are made between the employers and Union representatives, subject to revision every six months. Generally speaking, the provisions for welfare would not be regarded as onerous in other civilised countries, but considerable difficulty is introduced owing to restrictions surrounding the discharge of employees, the determination of what constitutes a day's work, the matter of annual vacations with pay, and other matters. The working day consists of seven hours, with extra compensation for any work carried on after that.

Enough has been said to show that the question of an uninterrupted and sufficient supply of manganese ores is one of vital importance, not only to the metallurgist, but to the world generally. The metal manganese is one without which the production of modern steel cannot be carried on satisfactorily. As compared with iron ores, the sources of supply of manganese ores are few in number and the deposits much smaller. Some day it may be that, as a result of persevering research, methods will be found of removing oxides and oxygen or other occluded gases from steel without the use of manganese, but so far there is nothing in sight to show that this can be done.

In this connection, although the supplies of iron ores are still enormous, there are those who are already discussing the question of their shortage. For example, it has been stated by no less an authority than Mr. W. O. Hotchkiss ⁽¹⁾, President of the Michigan College of Mines, Houghton, Michigan, that in about twenty years the present apparently vast supplies of merchantable grades of iron ore in the Lake Superior district will be exhausted; the iron ore shipments from this source have already amounted to 1,250 million tons. This subject,

⁽¹⁾ *Journal of the American Institute of Mining and Metallurgical Engineers*, 1926, p. 339.

like the supply of manganese ores, becomes invested, as Mr. Hotchkiss says, with a lively interest to a vast group of people, concerning, as it does, the livelihood of some eight millions of persons depending on these industries.

The high-grade manganese ore produced constitutes less than 2 per cent of the total amount of manganese ore consumed, so in that country, if the importation of high-grade ore and the alloys produced therefrom were discontinued, numerous industries there would be affected in a vital manner.

In an article by Mr. Olin R. Kuhn ⁽¹⁾ there is given a complete table of analyses of the world's manganese ores, known at that period. It is also stated that about 95 per cent of the manganese ore produced in Brazil comes from the Minas Geraes district, about 150 miles northwest of Rio de Janeiro. It was first discovered about the year 1880.

With regard to the supply of manganese ore from the Gold Coast, the African Manganese Company, Ltd., exhibited samples from the ore to the finished product at the British Empire Exhibition held at Wembley in 1924 and 1925. The developments made by this company have been most remarkable, and manganese ore now forms one of the principal exports from the Gold Coast. The deposits were discovered by the Geological Survey in 1914, but were not developed until 1916.

In an address by Sir Albert E. Kitson ⁽²⁾, Director of the Gold Coast Geological Survey, much useful information was presented with regard to the resources of that district, including those relating to manganese ores. The Gold Coast has an area of some 80,000 square miles, including the Gold Coast Colony 23,500 square miles, Ashanti 24,600 square miles, and the Northern Territories 30,600 square miles. In view of the importance of the statements made, the author quotes somewhat fully from Sir Albert Kitson's paper, in which he states that there are three types of manganese deposits—all of them occurring on the strikes, mainly northeast to southwest, of certain beds in the Birrim series, underlying the Tarkwa series, which is probably pre-Cambrian in age.

⁽¹⁾ "Surveys Manganese Ore Supply," *Iron Trade Review*, Aug. 18, 1921.

⁽²⁾ "The Mineral and Potential Water Power Resources of the Gold Coast, with Remarks on Prospecting Methods." Address at Winchester House, Sept. 1926.

These deposits are described as:

- A. Manganese-bearing argillaceous phyllites and fine mica-schists, with subordinate silicious phyllites. These rocks are only slightly altered, and the manganese oxide is in the form in which it was originally deposited in the sediments.
- B. Spessartite (manganese garnet)-quartz rock, with or without rhodonite (manganese silicate), associated with biotite-paragneiss, biotite-schist, amphibolite, &c. These are highly altered forms of group A.
- C. Segregation deposits formed by surface concentration of manganese oxide during weathering of rocks of A and B types. The special economic importance of the manganese deposits is dependent upon the degree of concentration that has taken place.

These deposits occur in numerous districts in the Gold Coast Colony, Ashanti, and the Northern Territories. Owing to folding of the sediments they are visible at many places from the Birrim river, near Dixcove, on the coast to the northwest corner of the Northern Territories, for a distance of some 440 miles.

The largest deposit occurs at Insuta-Dagwin, Gold Coast, where it forms the major portion of a high ridge, extending for about 2 miles by the side of the Sekondi-Kumasi railway at a distance of 36 to 38 miles from the port of Sekondi. This huge deposit consists of massive ore and of 'detrital' ore, the latter being composed of manganese oxide in grains and small to large nodules in a red clayey soil. The ore now being produced is of high grade, and is specially suitable for the manufacture of ferro-manganese. Much of it is of the best quality, and is used in the chemical industry.

The analysis of the average ore is:

Manganese	Iron	Silicon	Phosphorus
Per cent.	Per cent.	Per cent.	Per cent.
50 to 53	2 to 4	3 to 7	0.1 to 0.12

Figure 4, shows an outcrop of manganese ore at Insuta-Dagwin, as discovered by the Geological Survey in 1914, and Figure 5, gives a view of the Insuta manganese mine, showing washing plant and benches in ore.



Figure 4.—Outcrop of manganese ore, Insuta-Dagwin deposits, Colony, as discovered by the Geological Survey in 1914.

Sir Albert Kitson states that besides this deposit he has noted three occurrences of manganese ore in the northern portion of the Northern Territories—namely, at (1) about five miles east of Zuaragu; (2) about fifteen miles south-south-west of Zuaragu; and (3) about fifty-four miles east of Wa. The best of these on analysis showed only 12.50 per cent manganese. At none of the places at present known in the Northern Territories is the ore believed to be sufficiently rich in manganese to be of economic value, though some of the material from Kalimbi hill, near Siripe in the southwest, gave 46.10 per cent manganese. It is, however, quite probable that at some places, in addition to the huge deposit of Insuta-Dagwin, there will be found deposits of commercial value, since there are many thousands of square miles of forested and open country in the Colony, Ashanti, and the Northern Territories that have not yet been examined geologically.



Figure 5.—Insuta manganese mine, showing washing plant and benches in ore. Railway station and ore-loading bins are to the left, out of view.

The author understands that manganese ore (42 per cent manganese) has recently been found in the Belgian Congo.

The following are the shipments of manganese ore from West Africa for the years 1916 to 1925. The considerable fall in 1921 was due to the shortage of ocean transport:

	Tons
1916.....	4,300
1920.....	41,000
1921.....	7,000
1923.....	117,900
1924.....	255,400
1925.....	357,200

The total exports of manganese ore up to March 31st, 1925, were approximately 660,000 tons, having a value of about £1,237,000.

In the *Bulletin* of the Imperial Institute for November, 1926, it is stated that a large number of occurrences of manganese ore are known in Cape Province, Bechuanaland, and in the Transvaal, though some of them so far have not proved of much economic importance. The *Bulletin* also says that: "The most important deposits are those of lateroidal character associated with dolomite in the Krugersdorp district. The manganese occurs as psilomelane or pyrolusite, and the workings are a number of shallow pits in pockets of ore which are 100 yards or so across.

"Recently attention has been directed to the important deposits of manganese ore in the Postmasburg district, which have been known since 1922, and have been lately described by Dr. A. L. Hall ⁽¹⁾. They are situated about 100 miles west of Kimberley, and extend in a northerly direction from Postmasburg, having been traced for 40 miles along the Gamagara ridge. The ore is almost entirely psilomelane, and is in the form of a sheet up to 20 feet thick interbedded in slates and iron-bearing conglomerates. Assays indicate a manganese content of 42 to 58 per cent; 1.75 to 7 per cent of silica; 3.25 to 10.9 per cent of iron; and no phosphorus. Based on an average thickness of 4 feet, it has been estimated that 900,000

⁽¹⁾ "The Manganese Deposits near Postmasburg, West of Kimberley," *Transactions of the Geological Society of South Africa*, 1926.

tons of ore are exposed in residual cappings; while in the case of a certain length of outcrop of the bed of average width 8 feet, and assumed to continue to a depth of only 10 feet, there are 1,800,000 tons. These figures may be considerably multiplied, for, owing to minor folding, there are several outliers of the ore-body. Active development is proceeding, and the immediate construction of a branch railway line from Douglas seems warranted."

In a recent press communication from Johannesburg, it was stated that the Union Manganese Company of Johannesburg had signed an important contract with two large American steel companies, under which the latter obtain the right to work the manganese deposits near Postmasburg on a royalty basis. The deposits are said to extend for forty miles. Under the scheme it is stated that a large company will be formed in America, and that a railway is about to be built connecting the fields with the main line.

The latest reports respecting these deposits state that they are of high grade and contain as much as one thousand million tons of procurable ore. Should this estimate be found to be even approximately correct, the apprehensions so freely expressed in some quarters, and to which reference is made later, as to a possible future shortage of manganese ore, will prove groundless.

The American interests referred to are reported to have placed in the hands of the Government of South Africa a sum of £250,000 for the contemplated railway, and to have allocated no less than £2,000,000 for the purpose of developing the enterprise. Sir William Hoy, General Manager of the South African Railways, has declared "that the developments in connection with manganese deposits will stagger the country, which will shortly possess the largest manganese mines in the world."

Not long ago the author received a letter in which it was mentioned by a Sheffield settler in the Transvaal that about nine miles away from his farm at Piet Relief there were extensive deposits of manganese ore, containing about 46 per cent manganese, and that shipments have already been made from this source.

The Indian ore deposits are in the Central Provinces, Madras and Bombay provinces, Mysore, Bengal, and Lower Burmah.

The author is indebted to the Central Provinces Manganese Ore Company, Ltd., for the following information with regard to their mines. This company is the largest producer of manganese ore in India, and owns twenty separate mines in the Central Provinces, which are estimated to contain upwards of twenty million tons of high-grade ore. These present properties are able to meet all the demands upon them for manganese ore, and their capacity for production will be further increased as soon as a new broad-gauge railway, now being constructed, is completed. The ore from these mines is blended into what is known on the market as 'Oriental' ore, with an analysis of:

Mn	P	SiO ₂	Fe
51.00	0.105	7.50	6.50

The importance to the Empire of this company's reserves of high-grade manganese ore will be appreciated when it is remembered that the statement has been made that the West African deposits in the Gold Coast Colony have now passed into the control of American interests, and as have also the important manganese ore deposits in the Caucasus. The Brazilian manganese ore deposits, owing to their geographical position, naturally find their principal outlet in the American markets.

It is a point of interest that the Central Provinces Manganese Ore Company have recently allied themselves with four of the principal British ferro-manganese makers, so that a regular supply of high-grade ore is secured for this country.

Figures 6, 7, and 8 represent views of the Kandri and South Tirody mines:

Figure 6.—General view, looking NW. of Kandri mine, Nagpur district. The hanging wall AA is marked on the figure, as also is the footwall BB. The bed is roughly 100 feet thick, and consists of manganese ore of very high quality (about 54 per cent metallic manganese).

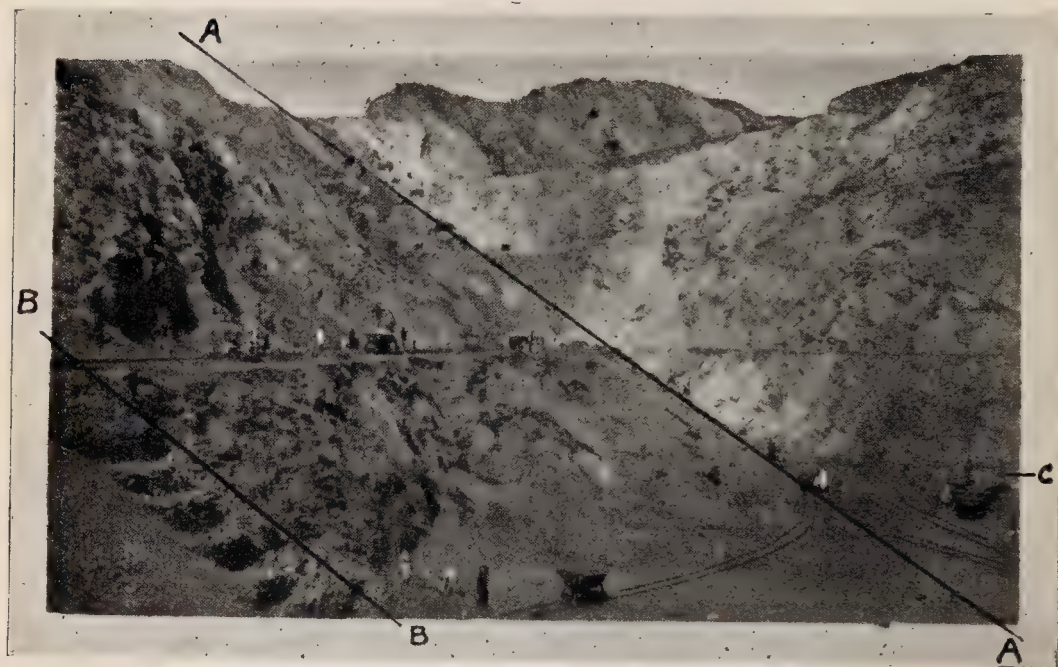


Figure 6.—General view of Kandri mine.

The bed dips at about 50° , and the overlying rocks are mica-schists. The bed is worked by horizontal benches 50 feet apart, and the truck in the foreground is at plain level. The bed has been proved to a depth of 170 feet below plain level by means of shafts, one being shown at 'C' on the figure.

Figure 7 shows a photograph of the Kandri bed at 'A' (Figure 6). The hanging wall AA is marked. The bed swings round to the NE. at the point 'B,' where the bed is much thinner than in the portion shown in Figure 6. The face 'C' is the footwall of the bed, which at this level has been worked out. The black spots 'D' and 'E' are trial drifts into the footwall to ensure that no ore has been missed. The black spot 'F' is a tunnel through the overlying mica-schists, which serves as an outlet for deads to the spoil dumps.

Figure 8.—View of part of the South Tirody mine, Balaghat district, looking west. This is taken from the footwall side of the bed. The footwall is shown at AA, and the bed dips away from the camera at about 45° . The ore is shown in this outcrop

and part of it has been worked off where the men are standing. This property is one of the largest in the Central Provinces, and contains ore of very high quality, running about:

Mn	P	SiO ₂	Fe
52.00	0.04	4.00	5.00

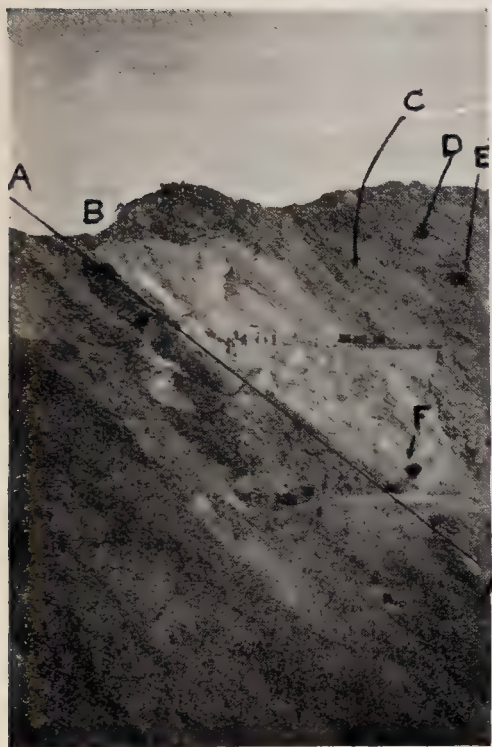


Figure 7.—Kandri bed.

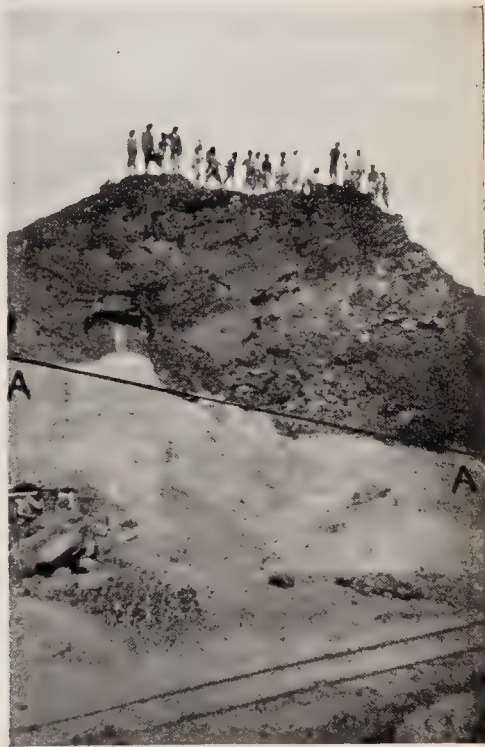


Figure 8.—South Tirody outcrop

It is interesting to note that ferro-manganese of 80 per cent grade has been recently made quite successfully by the Monterey Iron and Steel Company of Mexico, under the superintendence of Mr. D. J. Felkel, of this company's blast-furnace department. All the raw materials used in the manufacture of this ferro-manganese were obtained in Mexico, the manganese ore being mined in the States of Durango, San Luis Potosi, and Chihuahua.

In Japan there are manganese ore deposits, but the highest output was about 57,000 tons in 1918.

Manganese ores are also found in Cuba, Costa Rica, the Argentine, and in Chile, while deposits occur in China, in the Philippine Islands, and in Portuguese India.

The question of shortage of manganese supplies, whilst not immediately a serious one, may prove to be so in the not very far distant future. This has been one of the author's objects in preparing his present paper, so that interest may be aroused and attention paid to the subject. Metallurgically speaking, our world 'without manganese' would indeed be a sorry place.

This phase of thought is well illustrated by a pregnant paragraph in a paper on "Future Demand for Metals", recently read by Dr. H. Foster Bain, Secretary of the American Institute of Mining and Metallurgical Engineers. In this he mentions that an American writer, Mr. C. K. Leith, and others have pointed out how modern industry concentrates the pressure of its requirements on particular deposits, and misunderstanding or neglect to pay attention to these various sources is potent of international discord. As Dr. Bain says, one may be an optimist as to the total supply of any particular mineral in the world, and properly enough a pessimist as to its being brought out and made of use without friction among peoples unless great forethought be exercised. The author specially quotes these remarks because they seem to have considerable bearing on the subject of the sources of supplies of manganese ore.

There has been in the past a scramble for the gold-fields of the world, and today for the oil-fields; probably that for possession of the manganese ore-fields may prove to be quite as important.

There is no doubt that from the ferro-metallurgist's point of view the metal manganese ranks next in importance to the metal iron. The ordinary steel of commerce cannot be made satisfactorily unless containing from about 0.40 per cent to 1.00 per cent of manganese — that is, apart from the oxidised portion, this percentage should remain in the final steel product. Thus every million tons of such steel requires from about 9,000 to 12,000 tons of ferro-manganese containing 80 per cent of the metal manganese. Seeing that America alone is now

producing at the rate of over 45 million tons of steel per annum, whilst it is true much of this is produced from remelted scrap, it will be seen that the demand for the metal manganese must be very large. A striking illustration of this was shown in the war. In England, thanks to our Navy, we were kept sufficiently well supplied with the necessary manganese ores, but in certain other countries there was a dearth of such ores. So serious was this lack of supply that large quantities of steel were made containing very little manganese, or even in some cases none at all, the results often being most disastrous. Such steel was of the worst type, showing unsoundness, blowholes, and piping, with segregating material, in consequence, abounding to an unusual degree.

The following reference to the position of the United States in regard to supplies of manganese was made in a paper by Mr. F. H. Willcox, Metallurgical Engineer of the U.S. Bureau of Mines, Washington, read at the New York Meeting in February, 1917, of the American Institute of Mining and Metallurgical Engineers. This paper was commented on elsewhere ⁽¹⁾ just after the United States had entered the Great War, and it was stated that the Alloys Committee of the Council of National Defence had found that the U.S. was then consuming about 320,000 tons of ferro-manganese annually, made up of 240,000 tons domestic production and 76,000 tons importation. It was pointed out that it was not an agreeable commentary that America's greatest industry depended almost entirely on foreign sources for the ores with which to produce ferro-manganese. Also, that out of a total available supply of some 609,000 tons of manganese ore, only 33,000 tons came from the United States itself, while 82 per cent of the imports came from Brazil alone.

Secretary Lane (Secretary of the Interior) was asked what would happen if manganese ore imports were cut off, his reply being that "after America's own reserves were exhausted, a substitute would have to be found, and about this there was no question. This at first would cost more, but we (America) would have the steel."

(¹) *Iron Age*, June 14, 1917.

This may have been said to keep up courage amongst ferrous metallurgists, because although similar statements were then in circulation in Germany, various substitutes being mentioned — for example, calcium and its compounds, silicides, titanium, and others — not one of them proved to be a suitable substitute for manganese, and this fact remains unaltered today.

Now let us turn for a moment to the paper by Mr. Willcox, written at a time when “every nerve was stretched” to find a substitute for manganese.

Mr. Willcox showed that as all steel, Bessemer and open-hearth, contains more or less oxide of iron dissolved in the fluid metal at the end of the blow or heat, it is necessary to have some addition which neutralises part, or wholly removes such oxides. He says that as our knowledge then stood (1917), and it is pretty much the same to-day, it may be fairly said that the basis of modern steel-making lies in the several functions of manganese when added to steel as carburizer or deoxidizer.

In his paper Mr. Willcox refers to the situation of Germany in regard to this matter, and points out that Dr. Schroedter, about 1916, “mentioned, as a metallurgical experiment and secret, means by which Germany was able to get along with less manganese than formerly in steel-making.” What actually happened was that in Germany all the old piles of slag from ferro-manganese furnaces with manganese running from 5 to 14 per cent were rummaged; and it was reported that one village, Adensliddt, had been completely demolished to secure manganese ore running about 22 per cent manganese, so great was the need for any manganiferous material.

This shortage resulted in a great deterioration in the quality of the steel. These facts again show the exceedingly great importance of manganese to the metallurgical world. Germany appears to have realised this before the Great War broke out, as shown by the fact that during the year before 1914 she imported twice the normal amount of high-grade manganese ore from India and Russia.

The author hopes that our own Government will also take such steps as are necessary to have this matter brought to the attention of our own Committee of Defence, for, as pointed out by Mr. Willcox, good steel is impossible without manganese, that is, in the light of our present knowledge; he compares the situation with that of potash and nitrates. We in this country have taken steps in certain directions about these products; surely, therefore, we ought to do so about our manganese supplies.

The importance of the manganese situation is thoroughly appreciated in the United States, as shown in *Technical Paper No. 393* by Messrs. T. L. Joseph, P. H. Royster, and S. P. Kinney, on "Utilization of Manganiferous Iron Ores." This pamphlet is issued by the U.S. Bureau of Mines, Washington, and in it the authors state that the information compiled by the Mining and Metallurgical Society of America and the American Institute of Mining and Metallurgical Engineers, indicated that the reserves of ore containing 35 per cent manganese and upwards would only supply the domestic demand for about three years at the present rate of steel-making. The Committee in question was formed of the following members: Messrs. C. M. Weld (Chairman), D. F. Hewett, J. W. Furness, J. V. W. Reynders, John A. Mathews, Bradley Stoughton, and Robert Linton; assisted by Mr. Donald M. Liddell, Secretary of the Mining and Metallurgical Society of America, and Dr. H. Foster Bain, Secretary, and Mr. F. F. Sharpless, Secretary Emeritus, of the American Institute of Mining and Metallurgical Engineers. The report states that roughly 95 per cent of the total consumption of manganese finds its application in the manufacture of steel, adding that "no other element in available commercial quantities has yet been discovered which will perform the necessary functions in this connection as well as manganese, or at anything like an equivalent price."

The report further states that it was exceedingly desirable to take the necessary steps to prevent the recurrence of a shortage of manganese ore as happened in the Great War, and recommended it should be arranged that at all times large stocks should be kept in the country. The Committee went so far as to make the following important recommendations, which might be taken to heart as regards our own country:

(1) The necessary appropriations should be provided for purchase in the open market, in equal yearly quantities over a period of from six to nine years, of a total quantity of not less than 600,000 tons of ferro-ores, equal in grade to the accepted foreign standards; to be held in stock at a suitable location for tiding over a war emergency. This quantity is regarded as an irreducible minimum, being based on the assumption that in the event of such emergency it will be supplemented by forced domestic production, and by the customary stocks privately owned by certain large steel companies.

(2) The substitution of spiegel and high-manganese pig iron for ferro, and the investigation of possible substitutes for manganese, should be fostered and encouraged by every educational means at the disposal of the Government. The proper governmental department should be instructed to undertake an organized campaign in this direction, the necessary funds being provided, not only for the purpose of investigations and demonstration, but also for gathering and disseminating information. An experienced practical metallurgist should be in charge of this work, who should at all times keep his finger on the pulse of the country's requirements.

(3) Government experts, with the necessary funds at their disposal, should be required to maintain a perpetual inventory of all domestic manganese resources of whatever grade, at the same time keeping in active touch with foreign sources and developments. This work must go much further than a simple estimate of reserves in the ground; full information being constantly sought bearing on stocks in hand, the availability of reserves, the probable acceleration of domestic output in an emergency, the price that would be needed to bring it out quickly, the amounts that could be looked for, and so on; to the end that the domestic situation may at any time be appraised quickly and with reasonable accuracy, not only as to requirements, but also as to resources.

(4) Artificial stimuli in times of peace, which, if effective, will tend to deplete an already extremely limited reserve of ferro-grade and chemical ore, should be strongly discouraged.

The Committee stated that whilst they regarded all the above recommendations as of the greatest importance, considering that no one of them should be overlooked, they desired to call attention particularly to the first.

From the foregoing it will be seen how even the most wealthy nation in the world is dependent upon supplies of this important metal manganese. Steel of the requisite quality cannot be made without its use.

That the subject is regarded as one of high political importance is also shown by an article by Mr. Josiah Edward Spurr ⁽¹⁾, who refers to the various metals of importance to his country, commencing with manganese. He mentions the peculiar but important fact that Nature has distributed manganese ores in quite different areas from those in which she has segregated iron. In the Lake Superior iron ore district there are no manganese deposits of importance, and this applies to the second greatest steel-producing district in the world, Alsace-Lorraine. In the opposite direction there is no steel industry in Brazil or in the Russian Caucasus, or on the Gold Coast. India is the only country rich in manganese where a steel industry has begun to be established.

It was the necessity for obtaining outside supplies of manganese ores which no doubt moved American capitalists in 1925 to secure control of the Russian Caucasus manganese ore-field, which region is now being actively developed with American engineering talent and capital. During the Great War supplies of manganese from Russia were entirely stopped, and from India largely so, owing to lack of shipping facilities. Fortunately for America, however, there still remained the Brazilian ores, of which full use was made.

In 1918, the price of such ores rose to no less than about six times that of 1913. The United States made a splendid effort in developing its own resources, producing no less than 24 per cent of the high-grade manganese ore consumed, as compared with its 1 per cent pre-war figure. As Mr. Spurr points out, however, this production itself was at a killing pace, which it would have been impossible to keep up, and probably

⁽¹⁾ "Steel-Making Minerals," *Foreign Affairs*, July 1926 (American Monthly).

impossible to repeat. That the American efforts to develop home production of manganese ores were, as in other countries, prompted by a scare, is shown by the fact that, from 410 concerns and individuals producing such ores, no less than 461 claims for loss were filed with the War Commission. Moreover, at least one-third of the ore thus produced was at a financial loss.

In this same article Mr. Spurr reproduces an interesting diagram of the world's production of manganese ore from 1901 to 1920, which appeared in the Report of the Joint Committee of the two American Societies previously referred to in this section. This diagram is shown in Figure 9, to which the author has added the latest information available, that is, up to the year 1925. The figures for the years 1901 to 1920 are similar to those obtained by our own Imperial Mineral Resources Bureau, who have kindly provided the author with the information for the years 1921 to 1925. Table I gives the production figures for India, Gold Coast, Russia, Brazil, and the United States for those years.

Table I.—World's Production of High-Grade Manganese Ore.
(Thousands of tons.)

Country	1921	1922	1923	1924	1925
India.....	679	474	695	803	710
Gold Coast.....	7	66	140	233	339
Russia.....	28	193	237	492	513
Brazil.....	271	335	232	157	307
United States.....	14	13	33	57	76
Other countries.....	200	300	350	500	500
Totals.....	1,199	1,381	1,687	2,242	2,445

We are indebted to the Advisory Council on Minerals to the Imperial Institute, of which Sir Richard Redmayne is Chairman, and whose Secretary is Major Henderson Scott, for the excellent work being carried out by them.

In addition there is the tonnage of low grade ores to be added, namely, about 250,000 tons in 1925. The grand total of all grades of manganese ores in 1925 amounted therefore to about 2,700,000 tons, of which the British Empire produced 1,190,000 or 44 per cent.

In order to give an idea of the position of the manganese resources of the world, the author has prepared in Figure 10 a coloured map on which are shown: (*a*) The chief sources of supply, that is, those giving an output of over 100,000 tons per annum; (*b*) sources giving an output of over 10,000 and under 100,000 tons per annum; (*c*) sources with an output below 10,000 tons; (*d*) potential sources of supply, that is, sources not yet fully developed.

In the preparation of this map the author has drawn freely on the information given by the various authorities whose work has been referred to in this paper, including the Imperial Mineral Resources Bureau, Zereteli, Curtis, and others whose articles have appeared in the technical press. Although the information may not be complete, it is thought that the data presented represent generally the situation as regards the manganese ore supplies of the world.

Whilst discussing this important question of the available sources of supply of manganese ores, there appear to be discrepant opinions. Mr. A. H. Curtis, in his monograph to which reference is made later, states that "the Brazilian resources alone of these ores are estimated to be sufficient to supply the world's requirements for several centuries."

On the other hand, Mr. John V. W. Reynders, the well-known consulting engineer, and President of the American Institute of Mining and Metallurgical Engineers in 1925, is of the opinion that "the manganese ore deposits of the world as now known are extremely limited, adequate perhaps to supply the steel industry for a matter of forty or fifty years."

In this same connection, the Joint Committee of the American Societies in their Report on "International Control of Minerals," to which reference has already been made, rather support the view expressed by Mr. Curtis, that the

sources of manganese ore supply suitable for spiegel and high-manganese pig iron are abundant. Those for ferro-manganese are, however, relatively scarcer.

In a paper by Mr. Hubert W. Davis on "Iron Ore, Pig Iron and Steel in 1925," issued by the Bureau of Mines, Washington, it is stated that in 1925 the production of ferro-manganese in the United States was 259,780 tons, averaging 78.93 per cent manganese, and containing 205,046 tons of the metal manganese. To produce this there were used 519,139 tons of imported manganese ore, and 34,942 tons of domestic manganese ore. The quantity of manganese ore per ton of ferro-manganese made in 1925 was 2.133 tons, in 1924 it was 2.186 tons, in 1923 it was 2.243 tons. Of the imported manganese ore consumed in 1925, 207,238 tons were from Brazil and averaged 43.52 per cent manganese; Russia furnished 194,006 tons, averaging 48.17 per cent manganese; India, 68,326 tons, averaging 50.42 per cent; and Africa, 33,582 tons, averaging 46.97 per cent. The remainder was from Chile, China, Cuba, and Porto Rico, and averaged between 42.44 and 52.75 per cent manganese. The average manganese content of the total foreign ore consumed in 1925 was 46.41 per cent.

As showing the improved methods of practice, it may be stated that in the manufacture of such ferro-manganese there was recovered 80.44 per cent of the metallic manganese contained in all the ore consumed in 1925, whereas in 1918 no less than 10 to 40 per cent of the manganese in the ore was lost.

In 1925, ferro-manganese in the United States was made at eight different furnaces, by three different producers, and the average value per ton at the furnaces was \$101.78.

In addition to the production in the United States, in 1925 68,077 tons of ferro-manganese were imported; 45,192 tons came from the United Kingdom; 7,838 from Canada; 2,194 from Germany; 8,478 from Norway; and 3,162 from Sweden.

There was also produced in the United States 95,890 tons of spiegeleisen, the average value per ton at the furnaces being \$25.10.

For lack of space, the author can only deal briefly with the position of manganese in its relation to the mineral industry. Those who require more information will find this in the five *Bulletins* and *Monographs* of the Imperial Mineral Resources Department of the Imperial Institute. The following is a short synopsis of the *Bulletins* in question:

“Mineral Industry of British Empire and Foreign Countries, War Period. Manganese (1913-1919).”

This was compiled under the direction of Sir Richard Redmayne, Chairman of the Governors of the Imperial Mineral Resources Bureau, and covers the years 1913 to 1919 inclusive. It contains:

- (a) General and very complete information with regard to the various types of manganese ores, also the uses and values of manganese ores for metallurgical and chemical purposes.
- (b) World's production of manganese ores, including estimates of its reserves, the names of the districts representing the sources of supplies of manganese ores — Russia, India, Brazil, Gold Coast, Union of South Africa, and the United States; description of the sources of manganese ores in the United Kingdom, all on a small scale; consumption of manganese ores in the United Kingdom.

It shows that, like the United States, Germany is short of manganese ores, so that the metallurgists of that country have had practically to rely upon outside sources of supply. Many experiments were made in Germany during the war, when she was unable to obtain manganese ores, and when great efforts were made to find an effective substitute as a deoxidizer of steel.

It is pointed out in the pamphlet that amongst the “common deoxidizers tried were alloys of aluminium and silicon, while calcium, vanadium, uranium, and boron alloys were also used, although their cost was excessive and, when not assisted by one or more of the common oxidizers, the steel produced was not of good quality, in many cases useless. The greatest hopes were placed on calcium carbide, but persistent tests on

a large scale proved unsuccessful. It is there regarded as entirely unlikely that it will be found possible to replace manganese in the manufacture of steel, until some radically new discovery or invention occurs.

“Mineral Industry of British Empire and Foreign Countries, Statistics — 1919-1921. Manganese.”

A shorter pamphlet containing information with regard to the world's production, 1919-1921; summary of exports and imports, prices, and a list of statistical publications.

“Mineral Industry of British Empire and Foreign Countries, Statistics — 1920-1922. Manganese.”

Similar to the above, only covering a year later.

“Minerals of the Empire — Prepared for the British Empire Exhibition, Wembley, 1924.”

This pamphlet contains a useful chapter on manganese, showing that in 1913 our Empire produced about 35 per cent of the world's output of manganese ore. Also that, whilst considerable reserves exist in the Empire, the known deposits throughout the world are not numerous.

“Manganese Ores.” Monograph on Mineral Resources, with Special Reference to the British Empire. Prepared under the Direction of the Mineral Resources Committee of the Imperial Institute, with the Assistance of the Scientific and Technical Staff, by Mr. A. H. Curtis.

This monograph contains some 120 pages, and includes an excellent bibliography. Information is given with regard to the sources of supply of manganese ores within the Empire and in foreign countries. The mineral classification adopted is as follows:

“(a) *Pyrolusite*.—This peroxide, otherwise known as ‘black manganese,’ crystallizes in the orthorhombic system, but the common form is a pseudomorph after manganite. The bulk of the Russian (Caucasian) ore consists of pyrolusite.

“(b) *Braunite*.—This is an anhydrous sesquioxide of manganese, invariably associated with silica, whether mechanically mixed or chemically combined, the proportion of silica being sometimes as high as 8 or 10 per cent.

“(c) *Manganite*.—This is a hydrous sesquioxide of manganese, otherwise known as ‘grey manganese ore.’

“(d) *Hausmannite*.—This is a brownish-black mineral, very low in oxygen.

“(e) *Psilomelane*.—This is a hydrous oxide of manganese, with or without varying amounts of baryta and potash. It is the most abundant of the manganese ores found in India, constituting with braunite probably at least 90 per cent of the ore exported.

“(f) *Wad*, or ‘*Bog Manganese*.’—In general, this cannot be considered as a true manganese ore. It results from the decomposition of other manganese minerals. It is not so valuable as pyrolusite or psilomelane, but is sometimes used in the manufacture of chlorine and of the pigment umber, and possesses value when used as a flux.

“(g) *Rhodochrosite* or *Dialogite*.—This is a carbonate of manganese, often with carbonates of iron, calcium, and magnesium in varying quantities. The ore has been extensively mined in the French Pyrenees. It must be roasted for removal of carbon dioxide before being charged into the smelting furnaces; and as in the case of a comparatively pure ore this leaves an oxidized product considerably higher in metallic manganese than much of the oxidized ores exported, it would be advantageous, having regard to freight charges, that carbonate ore should be roasted before shipment, where suitable fuel is cheaply available.

“(h) *Rhodonite*.—This is a pyroxene belonging to the triclinic system, and is one of the less important ores.

“(i) *Franklinite*.—This is a manganiferous zinc ore of considerable economic importance, found at Franklin and Sterling, New Jersey, U.S.A. It is of varying composition, resembling magnetite in appearance.”

In a recent paper, Sir Thomas H. Holland ⁽¹⁾, surveys the resources of the British Empire in basic raw materials. He points out how desirable it is to study this vital question, and mentions that in America there has recently been inaugurated the systematic inquiry into the stocks of essential minerals, to which reference has already been made. A committee of specialists has been appointed, under the advice and guidance of the two leading mining and metallurgical societies in that country — in fact, they have been at work for five years in classifying their resources into four groups, namely:

- (a) Minerals existing in sufficient quantities even to warrant export, these including copper, coal, iron and steel, and silver.
- (b) Those showing adequate supply but with nothing to spare.
- (c) Those existing in inadequate amounts, thus making U.S.A. dependent upon outside or foreign supplies — including manganese.
- (d) Minerals almost entirely lacking and yet necessary to maintain their essential industries; these include nickel, cobalt, platinum, tin, and diamonds.

Sir Thomas Holland states that: "The precision and thoroughness with which this vital question of their country's needs is being treated gives us a lead which it would be dangerous to disregard. For this Empire the question of mineral supply is even more important than in America; for our chief manufacturing area and principal military base are in Great Britain, where we have only a fraction of the minerals that are now required, and where we have already depleted some of the stocks that once we had."

He further points out that a large number of minerals are essential for the maintenance of civilisation, and many of them cannot be replaced in the functions for which they are used. Minerals are wasting assets, and their consumption is annually accelerating to such an extent that a partial famine for some important substances will confront the next generation.

⁽¹⁾ "International Interests in Raw Materials," *Royal Society of Arts*, Nov. 10, 1926.

Therefore the only immediate policy to be adopted by the big manufacturing countries is to take careful stock of their mineral resources. It is probably easier to do this in the United States than within the British Empire, which consists of independent States separated from each other.

There are, however, enormous territories unexplored within our Empire, and we can safely view the future without alarm.

SECTION 6.—USES AND APPLICATIONS OF MANGANESE ORES

Manganese ores find their chief application in the manufacture of the crude commercial alloys — ferro-manganese, spiegeleisen, silico-spiegel, and silico-manganese. Considerable amounts of manganese ore are likewise employed for mixing with iron ore burdens in the manufacture of pig iron from iron ores deficient in manganese, when the pig iron is required for steel-making processes. For the production of ferro-manganese the percentage of manganese in the ore burden should not, ordinarily, be below 40 per cent, and 50 per cent ores are to be preferred on the grounds of economy in coke consumption and regularity of working. The silica and alumina should be low and the phosphoric acid should not exceed 0.20 per cent. Associated metallic impurities, such as copper, lead, and zinc, are objectionable.

High-grade manganese oxides, of which ground pyrolusite (black oxide of manganese, MnO_2) is the most preferred, are used extensively for the manufacture of dry and other batteries. Their value for such purposes depends upon the amount of available oxygen present, which is, of course, a function of the amount of MnO_2 they contain, and it is upon this basis that they are bought and sold. The maximum, 18.4 per cent, is obtained with pure (100 per cent) black oxide. Some 35,000 tons of manganese ore are used annually in the United States alone for electrical purposes.

Pyrolusite is also used in the chemical laboratory for making oxygen, although its use for this purpose has been virtually abandoned. Manganese ores are used in the glass industry as decolorisers, the slightly violet tint imparted by

small proportions of manganese silicate being chromatically compensatory and complementary to the greenish-yellow tint due to traces of iron oxides in the sands used, and thus rendering the resulting 'metal' colourless. They are also used as colouring materials both in the glass and in the ceramic industries; in the manufacture of pigments and as oil driers; and in the chemical industries for the manufacture of the salts of the metal, which have extensive applications in pharmacy, the textile industries, and for other miscellaneous purposes. They were formerly employed to an extent greater than they are at present in the manufacture of chlorine.

Mr. A. N. Campbell ⁽¹⁾, of the University of Aberdeen, has investigated the possibility of the use of ferro-manganese as a material for anodes in electrolysis. The anodic behaviour of pure manganese and of an indifferent anode in a manganese electrolyte having been previously examined, it was thought that the anodic behaviour of ferro-manganese should be of considerable interest, in view of the fact that iron is a metal which exhibits the phenomenon of passivity very markedly, whilst manganese, at least under the conditions of Mr. Campbell's observations, is largely free from it. From the analogy between chemical and electrochemical passivity and the fact that ferro-manganese is comparatively stable, even in damp air, whilst pure manganese is not, a certain amount at least of passivity was expected.

Tests were carried out by Mr. Campbell on a specimen of ferro-manganese supplied by the author, and of the following composition: C, 6.90 per cent; Si, 0.66 per cent; P, 0.21 per cent; Mn, 77.90 per cent. It was found that although the material exhibited a very great passivity in certain electrolytes there is never complete passivity, both constituents — that is, the iron and the manganese — going into solution. Hence ferro-manganese is useless as an insoluble anode.

Mr. Campbell concludes that if any parallel can be drawn between electrochemical passivity and chemical behaviour it would seem that the stability of ferro-manganese under ordinary

⁽¹⁾ "The Anodic Behaviour of Ferro-Manganese," *Transactions of the Faraday Society*, Sept. 1926.

conditions is not a very deep-seated phenomenon, since the passivity can be readily destroyed, notably by rise of temperature.

Referring to its use in the manufacture of steel, that is, other than manganese steel, manganese is a metal which takes up the oxygen present in the molten steel, and the slag formed is more fluid and passes away more readily than when either silicon or aluminium, or both, are used for the purpose of removing the oxygen. Moreover, the unoxidized manganese, which is usually considerable, remains in the steel and plays a useful part in helping to increase the elastic limit and tenacity, either in the cast or forged form.

Burgess and Aston remarked as far back as 1909 that "manganese is the universal cure-all, the tonic of the metallurgist. It is added as a deoxidizer and in sufficient excess (up to about 1 per cent) to minimise the effect of the sulphur present." Manganese is almost as useful when making castings as forgings. Although it is true dynamo castings of high permeability contain little or no manganese, for ordinary steel castings manganese is usefully employed, helping to avoid pulling or cracking when the casting is cooling down. In speaking of these functions of manganese Mr. Willcox in his paper, before referred to, classifies them as follows:

A. In foundry practice:

- (1) Its use as a deoxidizer and desulphurizer.
- (2) Its use to alter the constitution of grain in the metal.

B. In steelworks practice:

- (1) Its use as a deoxidizer.
- (2) Its use to impart certain static properties to steel.

The deoxidizing action is usually considered to lie in the greater affinity of manganese than of iron for oxygen, and the consequent seizing by the manganese of the greater part of the oxygen existing as dissolved oxide of iron. The manganese oxide thus formed is insoluble in iron and goes almost entirely into the slag, returning iron to the bath as metal. The usual additions of manganese do not entirely eliminate oxygen from

the steel, and probably have a small effect upon dissolved gases. Traces of oxygen are commonly taken care of by the addition of aluminium after the ferro-manganese addition, but the scavenging effect of manganese is nevertheless very strong, and it is this action, in addition to other functions, which makes its use so indispensable.

Another action of manganese, to which is due in part its value, is its behaviour with sulphur. As steel exists at the end of a blow or heat, the sulphur is present almost entirely as sulphide of iron. Microscopic examination shows iron sulphide to exist in steel largely as films between the metal crystals, a condition which gives rise to weakness and brittleness of the metal when hot—'red-shortness' due to the impairing of the closeness of texture and cohesion of the iron molecules. Manganese additions convert the iron sulphide to mixed sulphides. With the present low-sulphur specifications and fast practice, it may be doubted whether very much manganese sulphide separates out from the metal into the slag. It probably remains in very large part in the metal, but is found to exist as sharp or rounded inclusions instead of films.

A third property of manganese, which is lacking in other common deoxidizers, is that it raises the critical temperature to which it is safe to heat the steel, preventing coarse crystallization at high temperatures.

Mr. C. P. McCormack ⁽¹⁾ has likewise dealt with the same subject in a paper entitled "The Economics of the Cuyuna Manganiferous Iron Ores," in which a similar description is given of the functions of manganese in steel-making.

An interesting application of manganiferous iron ore of a somewhat special type, found at the Bristol mine, Crystal Falls, Michigan, and known as 'manganate charge ore', has been described in *Iron Age* of February 17th, 1927. Claims are made that by the use of this ore an appreciable decrease can be effected in the cost of steel-making — that is, a saving of the ferro-manganese, fluorspar, and limestone ordinarily employed. There is also a decrease in the slag action on the furnace lining, and finally the production of steel of better

⁽¹⁾ *Journal of the American Institute of Mining and Metallurgical Engineers*, February 1925.

quality is claimed. An interesting paper on this subject was read before the American Iron and Steel Institute at their October Meeting, and describes the use of high-manganese basic pig iron and manganiferous ores in open-hearth steel practice.

In the very early days of crucible steel practically no manganese was added, as shown by the following analysis made by the author some years ago on a specimen of the original Huntsman crucible steel:

Carbon	Silicon	Sulphur	Phosphorus	Manganese
Per cent	Per cent	Per cent	Per cent	Per cent
1.40	0.17	0.047	0.017	0.18

Later, about 1839, Heath introduced the use of what he called 'carburet of manganese,' prepared by the reduction of a mixture of black oxide of manganese and carbonaceous matter at a very high temperature. There was protracted litigation arising out of that method. Whilst the percentages so added were only small, it is apparent that even crucible steel for many purposes required the presence of a certain amount of manganese in order to make it forge satisfactorily.

One of the reviewers of the author's recent book, "Metallurgy and its Influence on Modern Progress," points out that in it, where reference was made to the crucible process, there was a curious slip, repeating, as he says, "an error into which most of the Sheffield makers fell at the time," namely, "that Heath introduced the use of black oxide of manganese into the process. What of course, Heath introduced was the use of the carbide, and the oxide was used only in the attempt to avoid Heath's patent. This had little or no effect on the steel, but was disastrous to the pots, and from time to time spilt their contents; an edifying reminder to steel-makers that patents should be respected."

SECTION 7.—PURE MANGANESE AND ITS HISTORY

Manganese is an element belonging to the long period of Group VII (the halogens) in the periodic classification, although it has little in common with the other members of this group, except for the fact that it forms a heptoxide (Mn_2O_7), the properties and salts of which closely resemble those of the

corresponding chlorine compounds. Its atomic weight is 54.93, and its atomic number 25. Although hitherto it has baffled most of the attempts made to prepare it in a condition of very high purity, specimens have recently been produced by Dr. W. Rosenhain, aided by Dr. Marie Gayler and others, at the National Physical Laboratory, containing 99.98 per cent manganese, the residual impurity, though exceedingly small, consisting mainly of carbon, which appears to be pertinaciously retained and to have an altogether exceptional affinity for the metal.

The difficulty of obtaining absolutely pure manganese accounts, in all probability, for the extraordinarily conflicting descriptions of it which appear in the literature on the subject. Thus, the usually accepted version of its appearance and properties is that given by Dr. Mellor in his text-book ⁽¹⁾, namely, that it is a grey metal, with a reddish tinge, like bismuth, and that it is brittle and harder than iron. Dr. G. M. Dyson, in a recent article on "Manganese, its Alloys and Uses" ⁽²⁾, describes it as having a faint pink tinge and as being "comparatively soft and easily polished." According to Zereteli ⁽³⁾, it "resembles iron in its aspect; antimony, in shining colour, and is very hard and very brittle." The pure metal as prepared by Dr. Rosenhain has a coarse silvery crystalline columnar fracture, with a yellowish tinge and patches of yellowish discoloration. Its hardness is stated to be as high as 550 Brinell, and it is exceedingly brittle. It scratches glass easily and is untouched by a file.

It is probable that the conflicting accounts of the colour, hardness, and specific gravity of the metal, which will be referred to at greater length later, are due to the impurities associated with most of the samples of so-called pure manganese which have been hitherto available, and upon the relative porosity and other physical characters of the metal resulting from the various modes of its preparation. It is possible, likewise, that the presence of hydrogen may, in some cases, account for the discrepancies. The author has tried to get rid of gases by heating specimens of manganese, but they remained unaltered.

⁽¹⁾ "Modern Inorganic Chemistry." London, 1925.

⁽²⁾ *The Chemical Age*, February 6, 1926.

⁽³⁾ *Op. cit.*

The New Elements Masurium and Rhenium

It may be interesting to add that, in 1925, there was announced the discovery of two new elements possessing many points of resemblance to the metal manganese, to which, therefore, reference may be well made in this paper. In the periodic table of the elements, manganese occurs in Period IV and Group VII, but in the same Group there had hitherto been found no elements to occupy the corresponding positions belonging to Periods V and VI, respectively.

In accordance with Mendeléeff's nomenclature, the names eka- and dwi-manganese — that is, the first and second elements after manganese — were assigned to the elements which, if eventually discovered, would occupy these positions. By application of the periodic law, the properties of these elements can be predicted with a fair degree of certainty, and, though naturally possessing distinct individuality, might be expected to resemble in many ways those of the metal manganese. It is these elements which it is claimed have been found.

W. Noddack, Ida Tacke, and O. Berg ⁽¹⁾, from reasoning based on theoretical considerations, concluded that the two missing elements of the manganese group might be looked for with some prospect of success in platinum ores and in certain rare earths. Their examination of platinum ores led them to separate a volatile oxide, whose connection with the elements in question was established by the examination of its X-ray spectrum. Both elements were found to occur in the mineral columbite, and by suitable concentration a product was obtained, the sublimate from which gave the lines of the new elements. The positions of these lines agreed well with the calculated values.

In an article entitled "The Occurrence of Dwi-Manganese in Manganese Salts" ⁽²⁾, V. Dolejšec, G. Druce, and J. Heyrovský state that, each working separately and by different methods, they have detected the presence of the second of these new elements in a different type of material, namely, salts of manganese.

⁽¹⁾ *Naturwissenschaften*, 1925, vol. xiii. pp. 567-574; *Sitzungsberichte der Preussischen Akademie der Wissenschaften zu Berlin*, 1925, p. 400.

⁽²⁾ *Nature*, 1926, vol. cxvii. p. 159.

Thus the identification of these two elements with the missing relatives of manganese is at present based only upon the agreement between their properties, so far as they have been ascertained, and those expected from the elements which should occupy these places in the periodic table. This identification is, however, apparently regarded by the discoverers with such certainty as to justify their being established among the known elements, under the individual names of masurium, and rhenium, respectively.

It is to be hoped that in due course the new elements will be isolated in sufficient quantities to enable a complete examination to be made, and thus to establish their existence upon an unassailable foundation. This is desirable not only on account of their interest, but also for the increased knowledge which a study of their points of resemblance to, and of difference from, the metal manganese is bound to provide, as to the true nature of the latter element.

SECTION 8.—PRODUCTION OF METALLIC MANGANESE

(a) *Early Processes*

Whilst Scheele, the great Swedish chemist, did not succeed in separating the metal itself from the manganese ore, his dissertation on the subject in 1774 was considered to be a masterpiece, and contained important discoveries in chemistry. It was at this date that manganese ore, MnO_2 , was proved by Scheele to be an oxide.

It is interesting to note that the renowned Swedish metallurgist, Sven Rinman, about the same time, 1774, was probably the first to note that manganese deprived iron of its usual magnetic properties.

The earliest process for the production of the metal manganese was that adopted by the Swedish chemist, Gahn, who reduced the dioxide with charcoal at a high temperature. To him, therefore, is due the credit of succeeding in isolating the metal manganese.

The experiments of Gahn represented a process analogous to that for the reduction, in similar circumstances, of iron, and the crude metal resulting was, like pig iron, contaminated with

carbon, from which it could be more or less freed by remelting it in contact with fresh pure oxide. The specific gravity of the material as produced by Gahn is said to have been 7.05.

This process, with modifications introduced from time to time by John, Faraday, and Berthier, for purifying the oxide, was carried out by making the pure oxide into a thick paste with oil, placing the mixture in a charcoal-lined crucible and covering it with powdered charcoal. Two or three hours' exposure to the most intense heat of a wind furnace or smith's forge sufficed to yield a button of metal, invariably containing notable quantities of carbon and silicon. Some of the carbon was removed by subsequently remelting, with borax as a flux, but the resulting metal was always contaminated with sodium and boron after the operation. The metal resulting from these methods was invariably described as greyish-white, lustreless, and rather soft and brittle. Its specific gravity, according to John, was 8.013.

Delville obtained the metal in 1856, by the reduction of red manganese oxide, Mn_2O_3 , with sugar charcoal insufficient in quantity to reduce the whole. He prepared the red oxide by heating the pure dioxide.

Brunner prepared metallic manganese by reducing the chloride or fluoride with sodium, in a manner analogous to that at one time employed for the preparation of aluminium. The resulting metal was brittle and very hard, being capable of scratching the best-tempered steel. It showed temper colours on heating, but was not oxidized even in moist air at the ordinary temperature. Its specific gravity varied from 7.138 to 7.206.

An alternative and highly successful method was described by Glatzel in 1889 ⁽¹⁾. He added stick magnesium to a mixture of manganese and potassium chloride, previously fritted at a moderate heat in a porcelain vessel. The residual manganese was hard, and its metallic lustre could be preserved for months in a glass-stoppered bottle, but the surface of the metal became light brown in colour if exposed to damp air. It was very hard and entirely non-magnetic, and the specific gravity was 7.329.

⁽¹⁾ "Darstellung von Mangan aus Manganchlorur und Magnesium," *Berichte der Deutschen Chemischen Gesellschaft*, vol. xxii., No. 14, pp. 2857-2859.

Many attempts have been made, with but little success, to obtain carbon-free manganese by direct reduction processes. Reference is made in Section 13 to the work, in this connection, of Roberts and Wraight. It is, however, of interest to call attention here to the alleged production of practically pure manganese by such a process, by Hugo Tamm, in 1872 ⁽¹⁾. He employed some special and carefully prepared fluxes, containing glass, quicklime, and fluorspar, his object being the direct reduction of the manganese from the ore instead of from purified oxide; lampblack was the form of carbon used. The result of the first reduction is said to have been a metal containing 96.900 per cent manganese, 1.05 per cent iron, 0.850 per cent silicon, and 0.950 per cent carbon. By further fusion with manganese carbonate the amount of manganese was raised to 99.910 per cent, with 0.050 per cent iron, 0.015 per cent silicon, and only 0.025 per cent carbon. The appearance, hardness and specific gravity of this very remarkable metal are unfortunately left unrecorded.

(b) *Modern Methods*

According to Dr. Dyson, the best method of preparing pure manganese is by the electrolysis of the chloride in saturated aqueous solution. The Annual Report of the National Physical Laboratory for the year 1924, however, states this process to be extremely laborious and the metal specially prone to oxidation. An alternative method has been adopted at the Laboratory. The impure metal resulting from the Goldschmidt electro-thermic process (in which the oxides are reduced by admixture with powdered aluminium) is remelted in a high-frequency electric furnace under a high vacuum, and the manganese which distils over in these circumstances is condensed, in layers, on specially designed condensers, and contains traces only of silicon and aluminium. It is by this method that the specimens of pure manganese referred to above have been obtained.

⁽¹⁾ "Metallurgy of Manganese and Docimastic Assaying of Manganese Ores," *Chemical News*, 1872, vol. xxvi. p. 111.

Manganese, in a pulverulent condition, has been obtained by the action of sodium amalgam on a saturated solution of manganous chloride. Giles ⁽¹⁾, who originally employed this method, obtained a brownish powder, which was, presumably, finely divided metallic manganese. The metal was also prepared by Moissan ⁽²⁾ in his electric furnace, but the current requirements were high and the process was not efficient, trouble being experienced, moreover, owing to the volatility of manganese at the high temperature of the electric arc. The production of ferro-manganese in the electric furnace will be discussed later in Section 12.

Royce and Kahlenberg ⁽³⁾ describe the preparation of metallic manganese from manganese amalgam. The method employed in the preparation of the amalgam was a development from those previously used by Campbell, Prelinger, and Neumann, and consisted in the electrolysis of a solution of carefully purified manganese salts, using a mercury cathode. A higher current density was found possible with a solution of manganese acetate than with the solutions of manganese chloride or of manganese sulphate and ammonium sulphate used by the previous workers. Amalgams containing up to about 4 per cent of manganese were thus obtained, and above 2 per cent were found to increase rapidly in their viscosity. Manganese in a finely divided form was derived from the amalgam by heating it in a current of hydrogen to a dull red heat, which volatilised the mercury and prevented oxidation of the manganese. By melting the powder in an atmosphere of hydrogen a specimen of manganese was obtained containing 99.60 per cent of the metal, which showed no tendency to tarnish after standing several months in the air of the laboratory.

Royce and Kahlenberg ⁽⁴⁾ have determined the electrode potential of manganese at 1.45 volts by experiments on its amalgam with mercury, and find that it will replace out of solution other metals whose potentials are more noble than that of manganese, including zinc, cadmium, iron, cobalt, nickel, lead, copper, and silver.

⁽¹⁾ *Philosophical Magazine* (4th Series), vol. xxiv. p. 328.

⁽²⁾ *Comptes Rendus*, vol. cxvi. p. 1429.

⁽³⁾ "The Electrode Potential and Replacing Power of Manganese," *Transactions of the American Electrochemical Society*, 1926, vol. 1. p. 137.

⁽⁴⁾ *Loc. cit.*

SECTION 9.—PROPERTIES OF METALLIC MANGANESE

(a) *Specific Gravity*

Reference has been made to the discrepant estimates of the specific gravity of manganese by various authorities. These results are tabulated below:

Table II.—Specific Gravity of Manganese according to Different Authorities.

Scheele and Gahn ¹	7.05	Bergman ⁵	7.0
John ²	8.013	Loughton ⁵	7.84 to 7.99
Brunner ³	7.138 to 7.207	Kuh ⁶	7.241
Glatzel ⁴	7.3921	Prelinger ⁷	7.421
Hjelm ⁵	7.0	Zereteli ⁸	7.7

Allowing for the fact that the temperatures at which the specific gravity determinations on early specimens of metallic manganese were carried out were very seldom recorded, the discrepancies shown in the above table are very considerable and unaccountable, except on the assumption that the specimens were contaminated with other elements, and, perhaps, sometimes by gases. There is a presumption in favour of such a hypothesis, as many of the methods employed in the preparation of metallic manganese would readily lend themselves to the occlusion of hydrogen. On the other hand, the National Physical Laboratory specimens referred to in this paper which have been distilled *in vacuo* should be free from hydrogen and other gases. It is noticeable that the specific gravities, in the case of the early specimens recorded by Scheele and Gahn, Bergman and Hjelm, are low.

(1) Quoted by Berthier, "Traité des Essais" (Paris, L. 834), vol. ii. p. 138, probably from Crell's "Die Neuesten Entdeckungen in der Chemie" (1774).

(2) Gehlen's *Journal für Chemie und Physik*, vol. iii. p. 452, and vol. iv. p. 436.

(3) *Poggendorff's Annalen der Physik*, vol. ci. p. 246.

(4) *Op. cit.*

(5) Quoted by Glatzel (*q.v.*).

(6) *Op. cit.*

(7) Wiener, *Monatshefte für Chemie*, vol. xiv. p. 358.

(8) *Op. cit.*

Lodoff ⁽¹⁾ found that manganese absorbs nitrogen and other gases containing nitrogen, such as cyanogen. Commercial ferro-manganese frequently occludes certain amounts of hydrocarbons, acetylene, also other substances, and accidents have arisen from this cause.

(b) *Melting Point*

The melting point of 99 per cent pure manganese is given by Heraeus ⁽²⁾ as 1,245° C. Mellor gives it as 1,225° C., and states that it boils at 1,900° C. As a result of tests made in the research laboratory of Messrs. Hadfields, Sheffield, it has been found that specimens containing 97.47 and 98.40 per cent manganese respectively both melt *in vacuo* at 1,240° C.

(c) *Specific Heat*

In the handbook of the American Society for Steel Treating there has recently been published a series of diagrams showing the heat content at various temperatures of several pure metals, including manganese. These diagrams are derived from the investigations of Wüst, Meuthen, and Duerrer, published by the German Engineers Society.

In Figure 11 the curve for manganese is shown in relation to those for iron, chromium, nickel, and cobalt. For each metal the angle of inclination of the curve at any temperature is naturally a measure of its specific heat, and it will be seen that generally manganese does not differ materially in this respect from the other metals mentioned over the whole range of temperature investigated.

Assuming a broader applicability, in an approximate way, of the law of Dulong and Petit which, referring to ordinary temperatures, states that the specific heat of an element is in inverse ratio to its atomic weight, these data therefore show that manganese has the quality in regard to its specific heat that might be expected. Its atomic weight (54.93) is, in fact, of much the same order as those of iron, chromium, nickel,

⁽¹⁾ *Journal of the Russian Chem. and Phys. Soc.*, 1903, vol. xxxv, p. 1238

⁽²⁾ *Zeitschrift für Elektrochemie*, 1902, vol. viii, p. 185.

and cobalt. For comparison the curves for aluminium and lead, of low (27.10) and high (207.10) atomic weight respectively, have been added.

It is interesting to note certain irregularities in the curve for manganese, in the range of temperature from about $1,050^{\circ}\text{C}$. upwards to its melting point, which in this case is apparently indicated at $1,210^{\circ}\text{C}$.

For most metals, and up to their melting points, the curve is smooth, and such is the case with chromium. Those for iron, cobalt, and nickel, however, display irregularities, clearly associated with the physical changes occurring in these metals at their well-known critical temperatures. The character of its curve would therefore seem to indicate something in the nature of a critical physical change produced in manganese by heating it above about $1,050^{\circ}\text{C}$.

(B) THE PRODUCTION OF FERRO-MANGANESE AND ITS HISTORY

SECTION 10.—THE ALLOYS OF IRON AND MANGANESE

The principal commercial alloys of iron and manganese are ferro-manganese and spiegel, including silico-spiegel. Ferro-manganese is a generic term for the crude pig metal containing in practice usually about 80 per cent. Spiegel ranges from 5 to 20 per cent, but the higher percentages are those for which there is most demand. Silico-spiegel contains 15 to 20 per cent manganese, and about 10 per cent silicon. All these materials contain carbon, averaging about 6 or 7 per cent in ferro-manganese, 4 or 5 per cent in spiegel, but usually less than 5 per cent in silico-spiegel. The presence of carbon is, in some respects, a disadvantage in experimental and research work, yet it is a curious and interesting fact that had the author been able, in the early days of his experimental work, to obtain high-grade ferro-manganese as free from carbon as is now possible, he might in all probability have missed making the discovery of manganese steel — a discovery which, in the opinion of many eminent metallurgists, has proved to be one of considerable importance, and of which the late Professor Floris Osmond said that it was one which ranked in the same order in the history of metallurgy as the discovery of the effect of quenching on carbon steel.

Table III shows the composition of several specimens of British ferro-manganese, spiegels, and silico-spiegels, and has been compiled from the "Memorandum on Iron and Steel at the Franco-British Exhibition," drawn up in 1908 by the late Professor Bauerman, and published in the *Journal of the Iron and Steel Institute* ⁽¹⁾ for that year.

Table III. Analyses of British Manganese Metal and Alloys

	Ferro-manganese		Spiegel			
	High man-ganese	Low man-ganese	High man-ganese	Low man-ganese	High man-ganese	Low man-ganese
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Manganese.	80.00	60.00	20.34	10.25	30.30	4.00
Carbon	7.20	6.40	4.95	3.82	5.50	3.50
Silicon	0.80	0.60	0.70	0.50	0.50	0.25
Sulphur	0.004	0.005	Nil	Nil	...	...
Phosphorus.	0.180	0.100	0.07	0.06	0.09	0.04
Iron	11.80	32.80	73.94	85.37	63.91	92.21
Metallic manganese						
Manganese.	90.35	90.50	92.20	95.30	96.00	97.85
Carbon	1.18	0.78	1.04	0.08	0.06	0.025
Silicon	0.92	0.49	4.96	1.40	0.60	0.64
Sulphur .....	...	...	...	...	0.208	...
Phosphorus..	0.27	0.30	0.36	...	0.068	...
Aluminium..	...	...	...	...	1.03	0.28
Iron .....	...	...	...	...	0.78	0.75
Low-carbon ferro-manganese				Silico-spiegel	Silico-manganese	
Manganese..	79.10	79.34	88.13	20.00	70.30	
Carbon	0.58	0.94	1.28	1.40	0.75	
Silicon	5.22	0.66	1.31	12.30	20.70	
Sulphur .....	...	0.017	...	Nil	...	
Phosphorus..	0.157	0.154	...	0.08	...	
Iron .....	...	...	...	66.22	...	

⁽¹⁾ 1908, No. III. pp. 336-412.

The following analysis of the interesting material, "manganese-magnesium-silicon," is appended for the purpose of comparison:

Manganese-magnesium-silicon		
	Per cent	Per cent
Manganese.....	11.70	19.00
Carbon.....	...	...
Silicon.....	26.70	36.50
Iron.....	3.50	3.80
Magnesium.....	51.00	34.60

In Table III are included the analyses of a number of special low-carbon ferro-manganeses, samples of pure manganese and other commercial alloys taken over a period of several years at the works of the author's company, and supplied by a number of different manufacturers. A high-grade (97.85 per cent) manganese from Messrs. Thermit, Ltd., is also included in the above-mentioned table.

SECTION 11.—HISTORY OF FERRO-MANGANESE

The author has from time to time dealt at some length with the history of ferro-manganese, but the following further information with regard to the early history of the production of spiegeleisen and ferro-manganese will no doubt be of interest to our members. The author is indebted for much of this to Kohn's "Iron and Steel Manufacture," published in 1868. This book contains a series of papers on the manufacture and properties of iron and steel; reports on iron and steel in the Paris Exhibition of 1867; reviews of the state and progress of the manufacture during the years 1867 and 1868; descriptions of the principal iron and steel works in Great Britain, the Continent of Europe, and the United States; also a concluding chapter, "The Manufacture of Iron and Steel in 1868," in which are embodied some of the important innovations which had been made after the volume was completed but not issued.

At the British Association meeting held in Birmingham in 1865, in the Mechanical Science section, as it was then termed, and preceded by an address from Sir William Armstrong,

President of the section, there appeared a paper on "The Manufacture of Cast Steel: its Progress and Employment as a Substitute for Wrought Iron," by Sir Henry Bessemer — that is, nine years after his first paper was read before the same Association. After dealing with the many difficulties to be overcome in the manufacture of his steel, he pointed out how, in 1839, the trade of Sheffield received an enormous impulse from the invention of Josiah Marshall Heath, in his patent covering the employment of metallic manganese, or, as he called it, 'carburet of manganese'. Sir Henry Bessemer then detailed the phases of the Mushet case, and finally added that "at the suggestion of the author (Bessemer) works for the production of manganese alloys were erected by Mr. Henderson of Glasgow, who now makes a very pure alloy of iron and manganese containing from 25 to 35 per cent of the latter metal, and possessing many advantages over spiegeleisen, which it will doubtless replace."

Sir Henry showed, at the reading of the paper, specimens of the steel made with the new Henderson alloy in lieu of spiegeleisen, which, he added, "is incapable of making steel of such a tough quality." Two bright rods, $1\frac{7}{8}$ inch in diameter, were exhibited doubled up cold under the hammer.

As showing the curious ideas then prevailing (1863), Mr. G. Parry, of the Ebbw Vale Ironworks, stated that, whilst he admitted manganese was a corrective of red shortness, it rendered steel more brittle while cold. In order, therefore to avoid having recourse to manganese, it would be necessary to employ more powerful machinery for rolling steel than was then generally in operation. No doubt confusion here came about with the higher carbon necessarily present in such steel in the days when only spiegeleisen was available.

In 1871, Ferdinand Kohn ⁽¹⁾, an original member of the Institute, read a paper on the production of alloys of iron and manganese. The position is there fully described with reference to the production of what was at that time an important metal known as spiegeleisen, obtained from the district of Siegen, in Rhenish Prussia.

(1) *Journal of the Iron and Steel Institute*, 1871, No. I. p. 70.

It is particularly interesting to note what was said by Mr. (afterwards Sir Henry) Bessemer in the discussion on Kohn's paper. He said that fifteen years previously (1856) "He had with some difficulty produced several pounds of metallic manganese entirely free from any alloy. Some of this metal he had added to pure decarbonized fluid iron, the result being the production of homogeneous iron of extreme toughness, which greatly resembled copper in its powers of extension and alteration of form without fracture, both in its cold and heated state."

Unfortunately, Sir Henry Bessemer did not mention in what way he had produced this metallic manganese, nor what were the percentages of manganese added to the iron; neither can the author find any other references to his experimental work in this direction.

From the information now presented, however, with regard to Sir Henry's work on manganese, it is apparent that, with his usual ability and foresight, he saw the enormous importance of the metal manganese, the practical applications of which he pursued with characteristic energy. It was without doubt largely his stimulation in this matter, especially exemplified by the energetic way in which he assisted in pushing forward the production of ferro-manganese by the Henderson process, which aroused so much interest in the development of alloys of ferro-manganese in contradistinction to spiegel, and led ultimately to the valuable applications of them which resulted. He was also the first to point out in his specification, in which he likewise described its manufacture, the benefits derived from the application to the Bessemer, and eventually to other processes, of steel-making, of the valuable alloy now known as silico-spiegel — that is, a combination of iron, manganese, and silicon — in place of the ordinary spiegeleisen.

Before the days of the introduction of the Bessemer and open-hearth methods of making steel, no one took much real interest in the application of the metal manganese or its compounds to ferrous metallurgy; in fact this element, for the type of steel then produced, was only required in what might be termed minute percentages. It has to be borne in mind that

at that time practically the only method of producing fluid steel was by the crucible process, and this was not more than about sixty years ago.

Steel melted and produced in this manner — that is, in the crucible — was not exposed to the same severe oxidizing influences as with the newer processes mentioned. Consequently manganese was not then so necessary.

It is true Heath had shown that during the melting operation crucible steel was improved by the admixture of what he termed 'carburet of manganese', and from which a certain amount of manganese was reduced and combined with the steel so produced. The percentage, however, was necessarily small, probably under 0.30 per cent, even if as much. This was due to several reasons, one being that any introduction of manganese in the crucible process related to steel containing high carbon, so that if too much manganese was employed the steel would not harden or temper properly without cracking. Consequently, whilst the addition of manganese in these earlier times might be beneficial in one way, it was not so from another point of view. When Sir Henry Bessemer introduced his pneumatic method a different set of conditions at once arose, and the employment of manganese became absolutely necessary.

In the Appendix to Kohn's paper ⁽¹⁾ he stated that the Terre Noire Company, then one of the largest and most successful Bessemer steelworks in France, employed a low percentage grade of ferro-manganese, produced by means of the Henderson process, and averaging from 23 per cent to 25 per cent of metallic manganese. It will thus be seen that this French development originated from the English process of Henderson, and no doubt that explains why this company later on, under the direction of Mr. Pourcel, were led to investigate the production of rich 80 per cent ferro-manganese in the blast-furnace, which they accomplished with great success, and thus finally solved this problem, one of the most important in ferrous metallurgy. The company's earliest production of such alloys was exclusively used for the softest Bessemer steel

⁽¹⁾ *Loc. cit.*

required for boiler plates, ship plates, the construction of ordnance, and similar purposes. The knowledge rapidly spread, and in this way was introduced the mild steel of today. Thus the successful production of a new ferrous alloy led to the development and application of steel in directions not previously thought to be possible.

A considerable number of mechanical tests were carried out on this boiler plate steel, made by the Terre Noire Company, by the late Sir William Fairbairn, who in those early days did so much to advance our knowledge with regard to the mechanical testing of iron, steel, and other materials. Many of these tests are given in detail in the Appendix mentioned above.

The average tenacity was about 27 tons per square inch, with about 30 per cent elongation and 57 per cent reduction of area. Sir William, in a letter dated November 10th, 1870, stated: "We have nothing comparable to it in quality in any of the manufactures with which I am acquainted." This was a glowing testimony to the value of the new type of steel alone made possible by the use of rich ferro-manganese in place of spiegel with its high carbon content.

Professor David Forbes also made many chemical analyses of these specimens for Mr. Kohn, and stated that the manganese was from 0.25 to 0.33 per cent.

Chemists of today will note with interest that Professor Forbes, in his Report dated March 25th, 1871, added rather naively as it seems to us nowadays, that "In the present state of chemical analysis, no thoroughly satisfactory process is known by which the true amount of manganese in an iron or steel bar can be determined when the quantity of manganese present is very small in relation to that of the iron, so that when this is the case, too much reliance must not be placed upon any analysis, however carefully executed." Fortunately the metallurgist has travelled a long way since then in laboratory practice, and consequently it is now possible to determine the percentage of this element in iron or steel with accuracy even when the amount present is under 0.01 per cent.

Mr. G. J. Snelus and Mr. Edward Williams made interesting contributions to the discussion on Kohn's paper. Mr. Snelus pointed out that the Ebbw Vale Company had succeeded

at that time (1870) in making spiegeleisen of very high class, as it was then termed, showing that such material could be obtained in England. He added that the production of spiegel containing 17 per cent manganese was considered a great feat.

As further showing the uncertainty and want of knowledge then prevailing, it may be mentioned that another of the contributors to the discussion on Kohn's paper, the late Mr. William Baker, the then well-known metallurgical chemist of Sheffield, stated that "as an analytical chemist he had satisfied himself that for some qualities of Bessemer metal manganese was not necessary, however useful it might be in producing it. He would call the attention of members to the fact that came out a year ago in connection with iron. When Heaton's process was under discussion, it transpired clearly that about 3 per cent of phosphorus might remain in iron provided silicon was absent."

A further contributor to the discussion was Mr. (later Sir) Lowthian Bell, who opened his interesting contribution by saying that

"The main fact they had to deal with was whether or not manganese was useful in the manufacture of steel. After the testimony they had received upon this point he thought it would be idle for anyone to pretend that the influence of manganese, either by its temporary presence or its permanent combination, was not productive of good; but he did not think they would be following out the exercise of their calling aright if they were to stop at the point of what does or what does not improve the quality of metal that they might be dealing with — they ought to know the reason why; but he was afraid the opinion expressed by Mr. Kohn in his paper, in explaining the use of manganese, could not be maintained. They had no information to justify them in coming to the conclusion that manganese promoted the separation of oxygen from the heated metal. There could be no doubt that heat does play a most important part in determining chemical combinations, and, further, that very same agent, by an increase of intensity, might be found to undo that which its presence had previously effected. For example, in the

well-known phenomenon of the combination of oxygen and hydrogen, the union between those two substances was considered within the last few years to be of that character that it was idle to expect that anything in the way of heat could undo that which heat had done, until one of the philosophers of the day, Mr. Grove, demonstrated beyond all doubt that by intense heat the elements of water could be dissociated. He supposed, if there be any truth in that which had just been advanced by Mr. Kohn, that some such influence must have been at work. They all knew that oxygen combined with great readiness with iron. Now the President himself (Mr. Bessemer) had mentioned to him, on the previous day, that there was one way of accounting for that, which, in his opinion, had never yet been satisfactorily proved, but supposing it to be so, that oxygen exists in steel in the Bessemer converter, that it might do so without being combined with the iron, and the President had instanced to him the well-known fact of the power of molten silver to dissolve in its substance an enormous quantity of oxygen. He maintained, however, that there was no analogy between the cases of silver and iron. They had no right to suppose that iron could dissolve oxygen gas. If it had the power to dissolve oxygen gas, he would ask what is the temperature at which the oxygen gas commences to act, and the time at which it ceases to combine and only be dissolved? The matter evolved, and forming the air-bubbles, must be given off when the iron is cooling; therefore, to suppose that oxygen, having been dissolved by superheated metal, should be able to give off oxygen at a temperature when they knew that it combines most readily with that element was, he thought, a contradiction of terms."

Sir Lowthian Bell conclusively proved, with unusual foresight, as might have been expected from so eminent a metallurgist, that the presence of manganese was of great benefit. He added:

“Therefore, until they had some better means of testing that oxygen can exist dissolved in the iron, he must for one dissent from the statement that the office played by manganese is that of freeing it from oxygen in solution merely.”

Such were the beginnings of the manufacture of mild steel, which has revolutionised the world by enabling constructions to be produced which were not before possible. This was all due to the metal manganese and its wonderful effect in improving the quality of the steel, a matter which nowadays we take for granted. It is therefore interesting to see the gradual steps which led to this important advance in metallurgical practice.

There is no doubt to-day about the great importance of manganese, not only as regards cleansing steel from the oxygen or oxides present, but to some extent on account of the physical properties it confers upon iron itself.

Kohn, in his book, when describing the production of spiegeleisen, made the following interesting statement, which it is useful to note even to-day:

“To a practical steel-maker in Sheffield who buys his ‘spiegel’ in Hull, or delivered into his own yard as the case may be, nothing appears more clear than the precise nature of this material. It is simply common pig iron containing about 6 per cent manganese and 5 per cent of combined carbon. If it contains more manganese, all the better, because the manganese gives it the value for steel-making; and if it contains less than 6 per cent, well, then he will buy no more from the same source of supply, and there will be an end to further trouble and investigation.

“The principal localities for spathic ore in Europe are the Erzberg or ‘Ore Mountain’ in Styria, a mountain of the same name in Carinthia, and the Stahlberg, or ‘Steel Mountain,’ of Müsen in Rhenish Prussia. Brown ore, formed by the decomposition of spathic ore, exists in the mines belonging to the Georg Marienhütte, in Hanover, and in the vicinity of Schmalkalden, in Thuringia. Almost all the ‘spiegel’ imported into England is made in Rhenish Prussia, from the spathic ore of the Stahlberg.

“Attempts have been made artificially to increase the percentage of manganese in some kinds of iron by adding manganitic ores to the charge of the furnace. They have not, however, proved successful as yet, so that the percentage of manganese in the spiegeleisen may be said to be beyond the control of the ironmaster, so far as the production in the blast-furnace is concerned. The cost of production (1868) of coke spiegeleisen in the Siegen district is about £3 15s. per ton: the transport to England generally takes the course down the Rhine, and considerably enhances the price of this material.”

With regard to the then early production of ferro-manganese, it is stated in Kohn's book that the manufacture was commenced at the suggestion of Sir Henry Bessemer, by Mr. W. Henderson, of Glasgow, who invented a process, taking out a number of patents between the years 1860 and 1869 for the production of alloys of iron and manganese containing a high percentage of the latter metal, consequently with a lower ratio of carbon content to the percentage of manganese present, thus enabling a softer and milder steel to be obtained — a point which is referred to later on in this Section when considering the early work done by Mr. Pourcel with ferro-manganese produced in the blast-furnace.

It may be of interest, therefore, to see how this early production of ferro-manganese came about. It is a most interesting development, because it involves reference to the Bessemer process, which in its early days almost came to grief, owing to ignorance of how necessary the use of manganese was for its success.

As the writer of the recent article in the *Sheffield Daily Telegraph*, on the “Bessemer Anniversary,” states: “The inventor of the process, Sir Henry Bessemer, was born in Hertfordshire, of Huguenot stock (1813-1898), and when forty-three years of age first described his process in a paper entitled ‘The Manufacture of Malleable Iron and Steel without Fuel,’ read before the Meeting of the British Association for the Advancement of Science, held at Cheltenham on August 13th, 1856.” This paper was not received with much

enthusiasm, and the *Proceedings* of the Association did not even contain an abstract of it, merely mentioning the bare title of the paper without comment.

As Bessemer experienced difficulty in getting licensees to work his process, he set up in Sheffield, in 1859, the works which are still known as Messrs. Henry Bessemer & Company. The author's relative, Sir John Brown, was one of the first to become an important licensee under the Bessemer patents. It is stated that during the life of Patent No. 2639, of February 11th, 1856, Bessemer received over £1,000,000 in royalties alone.

In 1865, a further paper was read by Sir Henry Bessemer before the British Association on the "History of the Bessemer Process." It was there stated that, at the suggestion of the author (Bessemer), a small works for the production of manganese alloys was erected by Mr. Henderson at Glasgow, who then made a very pure alloy of iron and manganese containing from 25 to 30 per cent of the latter metal, and possessing many advantages over spiegeleisen.

Sir Henry Bessemer also stated, and his original words are quoted: "A Prussian gentleman, Herr Prieger of Bonn, had been successful in manufacturing a new alloy which he called ferro-manganese, consisting of 60 to 80 per cent of metallic manganese. It was found to be extremely useful in making malleable iron by the Bessemer process, in which spiegeleisen could not be employed on account of the large proportion of carbon it contained."

A Siemens furnace was erected for carrying out the Henderson process at the Phoenix Foundry, Glasgow. The process was worked by Messrs. Thomas Eddington & Sons, and consisted in reducing upon the open-hearth a mixture of carbonate of manganese and oxide of iron in the presence of excess of carbon by means of a neutral or reducing flame. The manufacture was commenced in 1865, apparently with good commercial results at first, and certainly with the greatest success as far as the quality of the product was concerned. The price of the metal produced by Henderson depended upon its percentage of manganese, namely, for each

percentage of the metal manganese contained in the ferro-manganese there was paid £1 per ton. The average price of spiegeleisen in England at that time was £7 per ton.

This manufacture of ferro-manganese was, however, prematurely discontinued as an unprofitable branch, notwithstanding the complete success from the technical point of view. Kohn says this was the only instance he could find at that time of a retrograde movement in the metallurgy of iron!

In view of the interesting historical references contained in the article, it will be useful to quote his words in full. They are as follows:

“The methods of manufacture carried out at the Phoenix Foundry consisted in mixing carbonate of manganese (a substance obtained in soda works as one of the products of the manufacture of bleaching powder) with an almost equal quantity of pure calcined ore, drawn from a copper works, in which it formed a kind of refuse. The original substance which yields this iron ore is a kind of iron and copper pyrites found in large quantities on the south coast of Spain. This ore consists principally of iron, copper, and sulphur, and each of these elements can be obtained from it by a special process. The ore is for this purpose calcined or burnt; the operation of burning it is at present very largely carried out at the St. Rollox Works, Glasgow, where one of the largest and finest apparatus for the manufacture of sulphuric acid is in operation. The residue is next passed into the works of the British Metal-Extracting Company (Ltd.)—a company formed for working some of Mr. Henderson’s patents for an improved method of extracting metallic copper from its ores.

“The iron ore obtained as a residuum or waste product from the copper works was the second raw material employed by Mr. Henderson for making ferro-manganese. The two substances, namely, carbonate of manganese and oxide of iron, were mixed with charcoal powder or coke dust, and the whole mass charged without the use of crucibles into the Siemens furnace. The reduction of both metals, iron and manganese, took place simul-

taneously, and the percentage of manganese increased with the temperature, but not with the quantity of manganetic matter put into the charge; all surplus of the latter going into the slag, and eating through the firebricks of the furnace in a remarkably short time. This destruction of bricks by the chemical action of the manganese slag was, in fact, the great trouble and difficulty in this process. It went so far that the powder carried into the regenerators by the current of gases, and afterwards heated when in contact with the bricks, melted and even destroyed these portions of the furnace, and necessitated frequent repairs. The bottom of the furnace was lined with coke dust and graphite, and this stood better than the exposed surfaces of the firebricks in the other portions.

“The metallic alloy of iron and manganese produced ranged in its percentage of manganese from 17 to 30 per cent, and it was very free from other impurities.”

It is interesting to note the somewhat curious views held by metallurgists at that time (1868) with regard to the properties of the metal manganese and its effects in practice. In his book, Kohn said:

“Manganese induces crystallisation in large crystals divided by smooth cleavage planes, such as characterise the spiegeleisen and ferro-manganese. The presence of manganese in steel is therefore noxious, and far from being a cause of ductility and softness, as has been frequently supposed. The addition of manganese, which is supposed to give Bessemer steel its ductility and softness, has another meaning and purpose altogether, and Bessemer steel does not contain any sensible quantity of manganese. In this case the manganese is added only for the purpose of removing any surplus oxygen from the decarburised hematite iron. This iron, with its surplus oxygen, which has the quality of red-shortness, we would be almost tempted to call ‘oxygen steel,’ in strict analogy to our general term. The addition of spiegeleisen to this latter substance converts this into carbon steel by taking out the oxygen, which, in combination with the manganese,

goes into the slag, and replacing the oxygen by carbon. Ferro-manganese has the same effect, only the quantity of carbon contained in it, and given by it to the steel, is smaller, and therefore the carbon steel so produced is of a softer kind."

Kohn read his paper before the Iron and Steel Institute in 1870, at the meeting held in Merthyr Tydfil, and presented a further note on this at the Annual Meeting in London in March, 1871. His book, entitled "Iron and Steel Manufacture," published in 1869, was certainly unique at the time and contained exceedingly valuable and useful information to the metallurgists of that day. The author can speak from his own experience of the valuable nature of the work, as in his own company's works at Sheffield some of the plant still in use there was designed from the information given in Kohn's book.

It may be safely stated that the credit for having successfully solved the problem of the production of ferro-alloys in the blast-furnace, and at prices commensurate with the needs of steel-makers for this material, belongs to Mr. Alexandre Pourcel and to his colleagues, Messrs. Valton and Euverte, at the Terre Noire, La Voulte and Bességes Foundry and Ironworks Company. Their experiments were, for the most part, carried out from 1875 to 1885.

To show how completely Mr. Pourcel had solved the problem of producing ferro-manganese — let it be remembered that this was nearly half a century ago, when chemical and metallurgical knowledge were in their earlier stages of development — the author gives the following data, obtained from a translation he made at that time of the particulars given in the Terre Noire Company's brochure issued at the Paris Exhibition of 1878. It may be said that present-day products are practically the same as Mr. Pourcel was able to provide so long ago.

Mr. Pourcel himself, with characteristic modesty, assigns the actual credit for the first successful attempts experimentally to make ferro-manganese to Prieger, of Bonn ⁽¹⁾, who made the material in a crucible. It is to be remarked, however, that

(1) *Le Génie Civil*, vol. vii. pp. 3-5, 21-23, and 50-52.

Table IV.—Specimens of the Ferro-Manganese Exhibited by Terre Noire Works in 1878

	Analysis					
	Fe	Mn	C.C.	Si	S	P
Ferro-manganese (25 per cent Mn)	69.60	25.15	5.20	0.052	...	0.095
“ (33 “ “ ) . . . .	...	...	...	...	...	...
“ (41 “ “)	53.00	41.25	5.45	0.080	...	0.135
“ (50 “ “ ) . . . .	...	...	...	...	...	...
“ (64 “ “)	30.50	64.25	5.65	0.062	...	0.125
“ (66 “ “ ) . . . .	...	...	...	...	...	...
“ (72 “ “ ) . . . .	...	...	...	...	...	...
“ (77 “ “ ) . . . .	...	...	...	...	...	...
“ (81 “ “ ) . . . .	...	...	...	...	...	...
“ (85 “ “)	8.25	85.20	6.62	0.093	...	0.145

as far back as 1830, or thereabouts, David Mushet had made a material of the kind that would now be regarded as a ferro-manganese of low grade, and, as already mentioned, similar products were being made on a commercial scale as far back as 1865, in Glasgow, by W. Henderson. The work of Mr. Pourcel was, however, on quite a different scale and resulted in the material which, by the crucible process, cost no less than £80 to £100 per ton, or by Henderson's process, about £56 per ton, being at once reduced to £16 per ton—a truly remarkable achievement at the time. This figure was later reduced to the extraordinarily low selling price of about £8 per ton.

In view of the historic importance of the original work by Robert Mushet, who resided at Coleford, Gloucester, the author thought that it would be well worth while and of general interest to present a few remarks on this phase of the development of the use of manganese in ferrous metallurgy. Various records show that Robert Mushet and his father, David Mushet, were much interested in experiments with this metal. David Mushet's book, published in 1840, entitled "Papers on Iron and Steel, Practical and Experimental—A Series of Original Communications made to the Philosophical Magazine,

chiefly on those Subjects," gives an account of a number of his experiments, and singularly enough, in some of them the non-magnetic qualities of the material produced are mentioned. There is no doubt, however, that these specimens were more in the nature of spiegel than ferro-manganese.

Chapter XV of the book contains quite a number of experiments to ascertain whether manganese may be alloyed with iron. In describing a large number of the experiments, David Mushet stated that he melted cast-iron boring dust with black oxide of manganese, but found that it was very difficult to combine the metallic manganese present in the oxide with the cast iron that he employed. He then tried further experiments, substituting manganese ore for the black oxide of manganese, the result being, according to his own words, "On the whole it appears doubtful whether in these experiments there was any real alloy of manganese with iron." On the other hand, in summing up, he mentioned that a number of the alloys he produced were very brittle, and that the magnetic force, as he termed it, possessed by the specimens was considerably reduced — in fact, as regards one specimen he stated that a magnet of the power of 20 lb. did not lift a globule of 180 grains.

It is not unnatural, therefore, when the development of Sir Henry Bessemer's process occurred, after the reading of his paper on "The Manufacture of Malleable Iron and Steel without Fuel," at the British Association Meeting held at Cheltenham on August 13th, 1856, at which time it was difficult to obtain a malleable product which would forge and roll properly, that the attention of many investigators was called to the subject and experiments were made.

It will be remembered that in Sweden the Bessemer process went ahead without much difficulty. This was no doubt largely because, in the first place, the molten pig iron treated by the Bessemer process and apparatus was, compared with the British and other irons, much lower in sulphur and phosphorus. There was still further the fact that Swedish pig iron contained manganese, consequently during the blowing of the charges by the Bessemer process the whole of the manganese was not oxidized, and therefore the product obtained

was really a decarburized iron or low-carbon decarburized iron, in which a certain percentage of manganese finally remained, thus greatly assisting the malleability.

There is not sufficient space in this paper to devote to this phase of the introduction of the Bessemer process, all full of interest. In any case, it will be seen how important the addition of manganese was to ensure the requisite malleability, whilst hot, of the steel produced, and to remove the red-shortness.

Robert Mushet saw this, and took out four patents for improvements in the manufacture of iron and steel, as follows:

No.	Applied for	Granted	Subject
2168	Sept. 16th, 1856	Dec. 30th, 1856	Improvements in the manufacture of iron
2219	Sept. 22nd, 1856	Dec. 24th, 1856	Improvements in the manufacture of iron and steel
2220	Sept. 22nd, 1856	Dec. 24th, 1856	Improvements in the manufacture of iron and steel
Provisional 3125	Dec. 19th, 1867	Not completed	Improvements in the manufacture of iron

A perusal of these patents shows that only Nos. 2219 and 2220, both applied for on the same date, September 22nd, 1856, and granted on the same day, December 24th, 1856, could have had any industrial value.

As regards the first one mentioned, No. 2219, in this we find a specific reference to the addition of a compound or alloy of carbon, manganese, and iron, purified or decarbonized—that is, blown material. Mushet also went so far as to say that he preferred to use the white crystalline cast iron. To quote his words:

“The triple compound or material of or containing iron, carbon, and manganese, may be conveniently and economically prepared by smelting into pig-iron or cast-iron metal in the blast-furnace with either coal, coke, or charcoal fuel, such sparry carbonates of iron termed

spathose iron ores, or such other ores of iron as contain, besides iron, a considerable quantity of manganese; and I prefer to use the white crystalline cast-iron metal thus obtained, and known in Prussia as *spiegeleisen*, for this white cast-iron metal, whilst it contains a large alloy of manganese, is more free from sulphur, phosphorus, and silicon than the grey pig iron obtained from smelting spathose manganesic iron ores, and I prefer to use such varieties of this white crystalline cast-iron metal as are found to contain a large alloy of manganese.”

In his patent he also points out the importance of using what he calls good pig iron or other cast iron of good quality, as free as possible from sulphur and phosphorus.

In the further patent, No. 2220, he also claims the use of metallic manganese as follows:

“When I intend to produce malleable iron, I purify the cast iron and decarbonize it thoroughly, or nearly so, and I then add to it a quantity of metallic manganese, varying from one-quarter of a pound to two pounds by weight of such metallic manganese for every one hundred pounds by weight of purified decarbonized cast iron, and I add the metallic manganese to the molten purified iron in the following manner, or in any other convenient manner — I stamp or crush the metallic manganese to the state of tolerably fine powder in any convenient manner, and which, as the metallic manganese is exceedingly brittle, may be readily effected, and I then strew the proper proportion of the metallic manganese thus pulverized upon or amongst the molten purified cast iron, either when tapped into the ladle or other vessel or furnace from the purifying furnace; or I place the pulverized metallic manganese in the ladle or vessel or furnace into which the purified decarbonized cast iron is about to be poured, and which purified decarbonized cast iron I then pour upon the pulverized metallic manganese, which, by the intense temperature of the said purified decarbonized cast iron, will be speedily liquefied and alloyed therewith, and the mixture is then to be poured into suitable moulds and treated in the usual manner.”

Many minds were turned to the new problems which were found to occur when introducing the production of steel in this novel manner.

Moreover, in this patent, Mushet foreshadowed the production of manganese in the blast-furnace, in the following words:

“The metallic manganese may be conveniently prepared or obtained by smelting the ores of manganese upon an ordinary blast-furnace blown with heated air, and using a considerable quantity of lime or limestone as a flux for the ores of manganese thus smelted”.

The foregoing notes bearing on the use of manganese in steel manufacture and in its specific bearing on the early history of Bessemer steel, may be further amplified by a reference to the words used in 1876 by the then President, Mr. William Menelaus, at the Annual Meeting of the Iron and Steel Institute on the occasion of the presentation of the Bessemer Gold Medal to Robert Mushet.

Mr. Menelaus commenced by saying that the iron and steel trades (1876) owed much to David and Robert Mushet. The son, Robert Mushet, to whom the medal was to be presented, had ably followed in the footsteps of his father. He then added the following words:

“It was needless to inquire very particularly what success attended Mr. Mushet’s attempts to improve old processes, because they were all overshadowed by the beautiful invention of the spiegeleisen process, as applied to his friend Mr. Bessemer’s great invention, and it was upon that ground that the Council resolved to pay Mr. Mushet the compliment that they then did. He thought they would agree with him that the application of spiegeleisen, in the way it was done, to Mr. Bessemer’s invention, was one of the most elegant, as it certainly was one of the most useful, inventions ever made in the whole history of metallurgy, and he thought it would be conceded also that for that alone, if for nothing else, Mr. Mushet well deserved the compliment they were about to pay him. It was an invention which was worthy of being associated with the great invention of Mr. Bessemer. The two inventions would go down together; in fact, the one was

the complement of the other, and he thought he was right in saying that no man in that room would be better pleased than his friend Mr. Bessemer that the Council had resolved to pay that compliment to Mr. Mushet. He thought it was a fit and seemly thing that the medal instituted by Mr. Bessemer should compliment the man who had made what he thought was really a brilliant invention. It had made the invention of Mr. Bessemer perfect, and probably would be used in England as long as Bessemer metal was made."

Sir Henry Bessemer then added a few words. He said that his, Mr. Mushet's, invention had supplemented his (Bessemer's), and that it was a most useful and valuable one there could be no doubt. There were reasons — he thought good reasons — why he did not acknowledge the validity of Mr. Mushet's patent. He would not, however, go into that subject. Mr. Mushet had never pressed the question against him, and he might say that for many years past both himself and Mr. Mushet had been perfectly in accord upon the subject; they had long since buried the hatchet, and he hoped and believed that they would entertain most mutual respect for each other. Such was the nature of this interesting episode.

In the past, manganese has indeed been a troublesome metal, being connected with several unpleasant differences. For example, to quote from Percy's "Metallurgy," and in reference to the legal proceedings in which Heath was involved in defence of his patent, "The result of fifteen years' litigation by Heath (in which no less than eighteen learned Judges, Privy Councillors and noble Lords took part) was that of eleven of the Judges, the Lord Brougham and the Lord Chancellor, seven were in favour of and six against the claim of Mr. Heath; of the eleven Judges who delivered their opinions to the House of Lords, at the final stage of the proceedings, seven were in favour of, and four against, the claim of Mr. Heath; and the House of Lords decided in conformity with the opinion of the minority."

Let us now turn to the equally interesting subject of how and why ferro-manganese developed in place of spiegel. This was described by Mr. G. Magniny, of the Fonderies, Forges et

Acéries de Saint-Etienne, in his interesting monograph presented in April, 1925, in connection with the celebration of the Sixtieth Anniversary of the entry into industry of Mr. Pourcel. It was there pointed out that steel ship-plates were produced from Bessemer steel in which spiegel was used to convey the necessary percentage of manganese. As the spiegel contained 5 to 6 per cent carbon, the steel produced was necessarily somewhat high in carbon, and the ship-plates so made often broke owing to lack of toughness in the steel. Mr. Pourcel, knowing of the existence of ferro-manganese prepared in the crucible, with carbon 6 per cent and manganese 60 to 70 per cent, therefore replaced the spiegel with ferro-manganese and produced a steel with only one-fourth the former percentage of carbon. It was thus in 1867 that the Terre Noire Company delivered the first ship-plates in mild Bessemer steel.

In working out this problem Mr. Pourcel was assisted by Mr. Valton, the chief engineer of the works in question. Their combined researches showed that steel with low carbon was much less brittle, and incidentally that it resisted sea-water corrosion much better.

Mr. G. Magniny pointed out that we in England were the first to carry out the reduction of manganese ore into its metallic form, ferro-manganese, by means of the reverberatory furnace; in the Henderson process installed in Glasgow, the method of producing ferro-manganese on a carbon hearth gave products much less costly than the ferro-manganese produced in the crucible. To use Mr. Magniny's own words, "This process, which constituted a real and marked progress, was installed at Terre Noire in 1869."

Then Mr. Pourcel, naturally desiring to reduce the cost of producing ferro-manganese, conceived the idea of solving the problem by establishing and installing methods of producing ferro-manganese in the blast-furnace. The great difficulty in the way was to avoid the lining of the blast-furnace being attacked, but, as Mr. Magniny says, the Henderson furnace method gave him the necessary idea, and that was quite sufficient, namely, to replace the silico-alumina bricks by carbon bricks. This idea was at once put into operation.

Full information regarding his experiments was published by Mr. Pourcel ⁽¹⁾ in a series of articles published in 1885; later reproduced by Moissan in Fremy's "Encyclopédie chimique." The account of the original research and practical metallurgical work which led to such important results to the world generally may be read there by those interested.

The author has prepared the following notes which embody, with certain interpolations of his own, the gist of Mr. Pourcel's interesting account, in the series of articles referred to above, of the experiments made at the Terre Noire Works. As, moreover, they refer to the work of Henderson and of Prieger, and show how that work laid the foundations of the successful manufacture of ferro-manganese at Terre Noire, they are of special interest in the present connection.

The articles in *Génie Civil* are described by Mr. Pourcel, who at the time of writing was Director of Steelworks in Bilbao, as "A monograph embodying the practical results of his own personal investigations and of those in which he had collaborated with others, including MM. Valton and Gautier." They relate to work carried out at Terre Noire during the period comprised between the years 1866 and 1883. Mr. Pourcel defines ferro-manganese as pig manganese containing over 25 per cent of manganese. Below 25 per cent of manganese, manganiferous pig iron is commercially termed *spiegel*, and when the percentage falls to between 5 and 7 per cent it is called 'small *spiegel*' (*petit spiegel*). He points out that at that time (1883) some metallurgical works only included in the term ferro-manganese pig metal containing 40 per cent of manganese and upwards, a classification he regards as purely fanciful. The line of demarcation depends, he says, upon the fact that the magnetic properties of iron are completely annihilated by the presence of 24 to 25 per cent of manganese. Thus, rich *spiegel* containing 24 per cent of manganese, when reduced to powder, still clings to a magnet, whereas when the percentage rises to 25 it is no longer attracted.

This line of demarcation between *spiegel* and ferro-manganese is sharply accentuated by a fact more tangible than any indication furnished by crystallization could be.

(1) *Génie Civil*, May 1885.

Indeed the lamellar fracture of spiegel, with large white and very brilliant plates, only becomes modified by gradual stages between 25 and 50 per cent manganese, and it is not until 50 per cent that they present decidedly the basilar crystallization or the amorphous grained texture, which becomes more and more distinctly marked in proportion as the percentage of manganese increases.

It is of interest in this connection to note in passing that as regards manganese steel, in which the carbon is only about one-sixth of that present in ferro-manganese, the line of demarcation in regard to magnetic properties occurs at a much lower percentage of manganese. Manganese steel of normal composition — that is, containing 12 to 13 per cent manganese, or only about half the percentage mentioned by Mr. Pourcel for ferro-manganese — is non-magnetic. Magnetic properties do not, in fact, appear to any appreciable degree until the percentage of manganese is lowered to about 7 per cent.

To revert to Mr. Pourcel's researches, he points out that Dr. Prieger of Bonn, by showing, in 1866, the possibility of making 70 to 80 per cent ferro-manganese of a few kilogrammes in weight, in graphite crucibles heated in a natural draught furnace, should be regarded as having inaugurated the manufacture of ferro-manganese, seeing that Henderson who, from the year 1863 had been making ferro alloys in a Siemens open-hearth furnace, had only made rich spiegel (20 to 25 per cent manganese). However, 'the Scottish chemist', as Mr. Pourcel points out, had reproduced conditions similar to those existing in the graphite crucible, by lining the hearth of the working chamber of his open-hearth furnace with bricks made of carbon.

It is curious that the patent taken out by Henderson in France, in 1863, for the manufacture of cast iron high in manganese did not mention the word 'ferro-manganese'. The mixtures referred to were vague, and Mr. Pourcel says the omission of an essential consideration, a carbon-lined hearth while making the alloys by the open-hearth process, is to be noted. Yet, in what was termed the Henderson process, that

feature — namely, the use of charcoal, coke, or retort carbon bricks for lining the furnace — was “the one thing that deserved mention.”

The phases of the manufacture of 80 per cent ferro-manganese at the Terre Noire Works were as follows:

At the beginning of 1868 it was made in crucibles. In the following year the Siemens open hearth was employed, and this method exclusively used until 1875. In that year the manufacture of ferro-manganese was commenced in the blast-furnace.

The Henderson alloys were first used for the production of mild Bessemer steel by Mr. Valton in 1865; in 1867 the new 80 per cent ferro-manganese was used in Bessemer steel for the first time, 20 kilogrammes being added to the casting ladle containing about a 3-ton charge. The ingots were remarkably free from pipe. Some of them were used at the works; others were sent to Fraisans, where they were made into sheets and subsequently exhibited with mention of the origin of the metal. Thus the Terre Noire Company were able to claim for themselves the application of ferro-manganese to the manufacture of mild steel, and the fundamental revolution which this wonderful metal — “described today as soft iron or blown metal” — was to produce in engineering constructions of all types already appreciated at that time.

Mr. Pourcel describes in detail the early practice at Bonn. The loss of manganese was considerable (50 to 55 per cent), and the cost by this crucible process was £130 per ton. At the Terre Noire Works the cost was even higher.

As regards the application of the Henderson process, this was carried on for no less than seven years at the Terre Noire Works, a full description of which is given by Mr. Pourcel, who says that although the process was an incomplete solution of the problem involved, it marked an important advance on the Prieger process. Nevertheless, the Henderson process helped to bring down the cost of 80 per cent ferro-manganese to about £56 per ton. At the time the article was written the cost at the Terre Noire Works, which by the open-hearth process had been £56 per ton, was brought down by Mr. Pourcel's research work to about £16 per ton in the blast-furnace.

Mr. Pourcel goes on to say that:

“The Prieger process could not in any way have become a commercial process, but it afforded us an opportunity of studying the mixtures, and it was Henderson who gave us the means of applying these commercially. It would be of little interest to recall, in this connection, the mixtures proposed by Henderson; they were all based on the employment of residues from chemical products: blue billy, manganese chloride, regenerated as carbonate or as oxyhydrate, &c. However, the cheapness of the raw materials did not matter much at first, the predominating question was the cost of manufacture, and particularly the means of obtaining the amounts of rich alloys required to produce mild steel on a large scale.”

As regards the manufacture of ferro-manganese in the blast-furnace Mr. Pourcel says:

“My Company (Terre Noire) commenced to see the possibility of the manufacture of ferro-manganese in the blast-furnace when we found that the Société Industrielle de Carniole had sent to the Vienna Exhibition in 1873 specimens of this product, obtained in the blast-furnace by treating a mixture of spathic ore and oxide of manganese.”

However, as mentioned by Gruner in his description of the exhibit, this ferro-manganese did not contain more than 30 per cent manganese, and the furnaces producing it could only do this for a few days without damage to the lining. Only lack of the necessary Cowper stoves delayed the Terre Noire Company from immediately following up the implied hint. This, however, was done in 1874, and interesting details of the furnace design and of the practice followed are given. Trouble was experienced with high-ash coke, but the difficulties were gradually surmounted, and a graphic account of the means whereby success was eventually attained is given in the article.

In connection with such details it may be of interest to point out the extreme importance of having proper refractories and furnace linings. The author has been favoured with some notes from Mr. J. M. Storey as to the type of bricks used by

the Darwen and Mostyn Iron Co., Ltd., in their own ferro-manganese furnaces. They contain approximately 55 per cent SiO_2 and 37 per cent Al_2O_3 , and are used with special clay. Such bricks have been found to stand up well to the work, and to be better than any others.

It appears that the work of Mr. Pourcel continued over something like three years before complete success was attained. The results were crowned with success in 1878 by very extensive work, and the production for the whole of one month of ferro-manganese containing 82 per cent.

Unhappily, in 1888, the Terre Noire Company, which did such splendid work in the advancement of metallurgy, and with which Mr. Pourcel had remained until 1883, closed down owing to financial difficulties.

Mr. Pourcel, who is now eighty-five years of age, is one of the distinguished Honorary Vice-Presidents of our Institute, and the author therefore thought it would be of interest to members to reproduce his portrait (Figure 12).

SECTION 12.—MANUFACTURE OF FERRO-MANGANESE

To give a detailed account of the manufacture of ferro-manganese would be beyond the scope of the present paper. It may, however, be pointed out that for its production in the blast-furnace high-grade ores are necessary, and that the process of smelting is apt to be expensive, not only because of the price of such ores, but also because the coke consumption of a blast-furnace working on such a burden is much higher than when ordinary iron ores are smelted for the production of pig iron. Three tons of coke per ton of ferro-manganese produced is by no means an unusual consumption, but with carefully selected ores and coke of the most suitable description the consumption may be brought down to about 2 tons per ton of ferro-manganese. The loss in manganese may, moreover, be considerable, particularly if the furnace is working at too high a temperature, when much of the metal may pass into the slag, and this is also liable to occur if insufficient coke is charged.



Figure 12.—Mr. Alexandre Pourcel, Bessemer Medallist.

The Joint Report of the two American Societies, to which reference has already been made, estimates the losses of manganese during smelting and kindred operations at from 15 per cent to as much as 35 per cent. The average loss at ferro-manganese furnaces operating during the war at the works of the Steel Corporation in America is said to have amounted to 28 per cent. That at 'spiegel furnaces' is said to have been higher (30 per cent).

Ferro-manganese produced in the blast-furnace almost invariably contains appreciable percentages of carbon, from which it is almost impossible to divest it. Ferro-manganese produced in the electric furnace can, on the other hand, be obtained with comparatively low carbon. Into the reason for this it would not be possible, within the limits of this paper, to go in any detail, and for similar reasons the effect of the presence of silica, lime, alumina, and phosphoric acid, on the working side of the charge, and that of such other impurities as zinc, copper, etc., cannot, in this connection, be further dealt with. It must suffice to say that high-grade ferro-manganese can be made in the electric furnace, the direct consumption of carbon in such processes being much lower than in the blast-furnace, and approximating to about 500 lb. per ton of ferro-manganese. It is claimed that the electric furnace yields a purer product, and that the nature and grade of the product are under better control. Electric processes are, however, not very efficient in other respects, and the product, owing to the heavy consumption of current, is expensive. The losses, due to the greater volatilization at the high temperatures employed, are also apt to be heavy, and the utmost skill and much experience are required in working an electric furnace for the production of ferro-manganese, if losses from these and other causes are not to become prohibitive. The cost of ferro-manganese produced in such circumstances is therefore higher than that of the blast-furnace product. The manufacture of silico-spiegel and spiegel is, however, almost invariably carried out in the electric furnace at the present time.

On the other hand, the production of ferro-manganese in the blast-furnace is the better and more economical process, although for certain kinds of work, where high purity is required, ferro-manganese produced in the electric furnace may have advantages.

The late Dr. J. E. Stead, in his Presidential Address to the Iron and Steel Institute in 1920, stated that the losses which occurred in smelting manganese ores amounted to 20 per cent. Apparently a similar figure applies to British present-day practice.

From figures kindly supplied to the author by the late Mr. F. Sutcliffe, of the Darwen and Mostyn Iron Company, it appears that, for each ton of manganese in the ore smelted, one ton of 80 per cent ferro-manganese is produced, containing 0.80 ton of manganese, thus representing a loss of 20 per cent. The larger part of the loss goes into the slag, and the remainder is carried away as flue-dust and vapour.

Mr. Sutcliffe stated that unfortunately the composition of the slag and flue-dust is such as to render the manganese content of little or no value.

As is well known, in reducing iron ore — for example, hematite — there is no appreciable loss of iron in smelting the pig iron.

The chief factor in determining the purity of ferro-manganese is the phosphoric acid content in the ore, rather than the process by which it is made. The author has had before him British ferro-manganese in which the phosphorus content is exceedingly low, so that by care and attention during the process of manufacture there is no doubt that the blast-furnace method can well hold its own.

The oldest electrical processes for the production of ferro-manganese are the Gin process and the Hofer process. In the former, dehydrated sodium sulphate is added to the ore, previous to its reduction by carbon in the furnace. In the Hofer process calcium fluoride is employed, and reactions take place in which both silica and phosphorus are volatilized and so eliminated. Ores which contain these constituents can therefore be treated by the Hofer process, although unsuitable for direct reduction in a blast-furnace. A pig of nearly pure manganese, weighing over 100 lb., and obtained by this process,

was shown at the Franco-British Exhibition, London, 1908, but, unfortunately, no analyses were forthcoming to show the composition of the material.

Dr. J. E. Stead, in his Presidential Address in 1920 already referred to, devoted one section to the consideration of the manufacture of spiegel and ferro-manganese. When speaking of the historical side and referring to the early days, about 1870 to 1875, he mentioned that in his own experience with the German and Ebbw Vale spiegeleisen at the Gorton Steelworks of Messrs. Bolckow, Vaughan & Co., Ltd., in 1872, the higher manganese in the latter made a great difference to the hot-working properties of the steel. Red-short cracks, common when the German material was used, practically disappeared, and, instead of having to cold-dress nearly every hammered bloom, little dressing was necessary.

He further stated that, following the advantage derived from the use of higher manganese, and with the availability of the manganiferous ores of south Spain, the Ebbw Vale Company soon produced material containing from 17 to 20 per cent manganese. Messrs. Bolckow, Vaughan & Co., Ltd., in 1873, at their Witton Park Works, were the first to produce a similar quality on the northeast coast. Other makers in Sheffield and elsewhere soon followed. Within a year or two little or no German spiegeleisen was used in the manufacture of rails in this country.

Then came Pourcel, in 1875, and, as narrated elsewhere, solved the problem of producing rich ferro-manganese in the blast-furnace, containing 40, 50, and eventually up to 85, per cent manganese.

This was fully confirmed by the wonderful exhibit of the Terre Noire Company at the French National Exhibition of 1878, when a complete collection of specimens of ferro-alloys produced by that company was shown, including ferro-manganese up to 85 per cent, silico-spiegel, and ferro-tungsten, all manufactured in the blast-furnace.

Great credit is due to British makers for the way in which they developed this important manufacture. Table V gives the names of the British makers of ferro-manganese, the number of furnaces they employ, and their capacity per

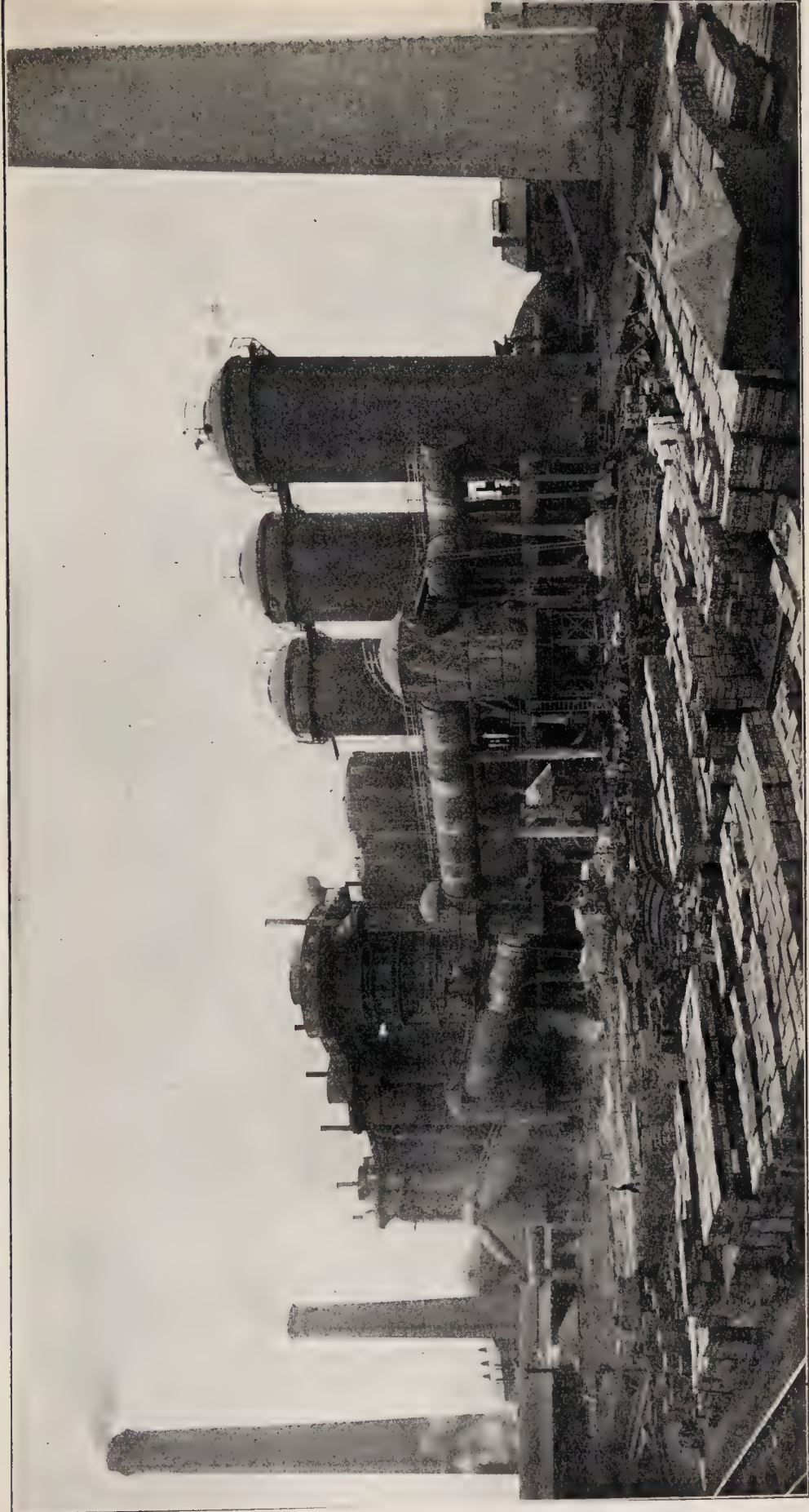


Figure 13.—View of works of The Darwen and Mostyn Iron Co., Ltd.

annum. It will be seen that the largest manufacturers of ferro-manganese are The Darwen and Mostyn Iron Co., Ltd., a view of whose works is shown in Figure 13.

Table V.—British Makers of Ferro-Manganese and their Output Capacity

	Number of furnaces	Capacity per annum Tons
The Darwen and Mostyn Iron Co., Ltd.....	5	75,000
Dorman, Long & Co., Ltd.....	2	45,000
Linthorpe, Dinsdale Smelting Co., Ltd.....	2	45,000
United Steel Co. (Workington Iron and Steel Branch).....	1	25,000
Bolckow, Vaughan & Co., Ltd.....	1	25,000
Wigan Coal and Iron Co., Ltd.....	1	25,000

The author thought it would also be of interest to give the analyses of ferro-manganese of the various grades used by his firm. They are shown in Table VI.

Table VI.—Analyses of Ferro-Manganese (80 per cent Manganese) in Various Grades

Source	Analysis									
	C	Si	S	P	Mn	Cu	Al	As	Fe	
	%	%	%	%	%	%	%	%	%	

Ordinary blast-furnace products.

'A'.....	7.07	0.76	0.027	0.20	79.1	...	..	...	12.84 ¹
'B'.....	6.89	0.60	...	0.29	79.1	...	..	...	13.12 ¹
'C'.....	6.80	0.78	0.029	0.276	80.5	...	..	...	11.61 ¹
'D'.....	6.90	1.34	...	0.266	79.4	...	..	...	12.19 ¹

Special products of high and low carbon.

Norwegian.....	6.94	0.21	0.014	0.18	78.5	0.016	..	0.046	14.1
Comptoir Général d'Usines (French Electric Furnace)	2.09	..	...	0.292	80.0 (estd.)	...	..	...	17.62 ¹
Ferrolegeringar (Swedish).....	0.94	0.66	0.017	0.154	79.34	...	..	...	18.89 ¹
St. Beron (French)..	0.58	5.22	...	0.157	79.1	...	..	...	15.03 ¹

Metallic manganese.

Thermit.....	0.025	0.64	...	...	97.7	0.23	0.28	...	0.74
Watsons.....	0.06	0.60	0.208	0.068	96.0	...	1.03	...	0.78
Blackwells.....	0.08	1.40	...	...	95.3	...	..	...	3.22 ¹
Hall & Co.....	0.11	..	...	...	95.28	...	..	...	4.61 ¹

¹ These figures represent iron by difference, and are necessarily approximate, owing to the presence in appreciable quantities of other elements not determined by analysis.

It may be interesting to add that amongst deliveries to the author's firm in 1892 was material containing no less than 88.88 per cent manganese, quite a metallurgical feat. In the early days of the manufacture of spiegel, which came from the Continent, it was thought quite a triumph to obtain 12, 16, or 20, per cent manganese in the spiegel.

As regards any improvement in the manufacture of ferro-manganese, there seems to be but little difference in the type and quality compared with that of the material which originated with Mr. Pourcel in 1875. The author, however, points out that it would be very desirable and useful if ferro-manganese could be produced containing under 0.05 per cent of the metalloid phosphorus. There is no doubt that for special purposes such a product would be of much practical service.

SECTION 13.—CARBON-FREE FERRO-MANGANESE

Many efforts have been made from time to time to obtain ferro-manganese in the blast-furnace free from carbon, or, alternatively, to submit the blast-furnace product to some process of refining which should have the result of getting rid of the carbon it contained. A valuable paper was presented on this subject to the Carnegie Scholarship Committee of the Iron and Steel Institute, in 1906, by two British metallurgists, E. G. L. Roberts and E. A. Wraight (¹). The paper covers a wide field, and while the results of the experiments recorded therein are inconclusive, a mass of interesting and valuable

(¹) *Journal of the Iron and Steel Institute*, 1906, No. II. pp. 229-286

information is given, together with many references to the work of previous investigators, and, in particular, to early researches on the production of the pure metal itself. So far, indeed, as purity is concerned, the material produced in the electric furnace is often quite low in carbon. The following is the analysis of a sample of a consignment of such material obtained from a Swedish firm by the author in 1921, and it shows that, apart from the question of carbon-free manganese, in the sense of the pure metal, ferro-manganese with less than 80 per cent manganese can likewise be obtained with a fairly low carbon content:

	Per cent
Manganese.....	79.34
Carbon.....	0.94
Silicon.....	0.66
Sulphur.....	0.017
Phosphorus.....	0.154

Reference to the analyses given in Table III further serves to show the extent to which the problem of producing carbon-free ferro-manganese may now be regarded as having been solved.

SECTION 14.—CONCLUSION

The author hopes that the information given in this paper will provide a useful addition to the literature on the subject of manganese and its industrial uses. The old Chinese proverb says, "They who own the iron of the world rule the world." It would almost seem safe to add that they who own the manganese of the world have largely in their hands the control of steel of satisfactory quality such as is now necessary to meet modern requirements.

Fortunately, Nature has spread the ores of manganese far and wide as they exist in the world—that is, they are not concentrated in one or two locations only, and cannot therefore be controlled by any one nation. The United States is now drawing large supplies of these ores from Russia, and is about to develop on a large scale newly acquired interests in Africa; Great Britain is developing her Imperial resources in India,

the Gold Coast, and South Africa; France, Germany, and Belgium derive their ores from a variety of sources. Singularly enough, no one country making steel on a large scale possesses the necessary supplies of manganese ore with which to make its steel. All are dependent on outside sources.

In conclusion, the author takes this opportunity of thanking Mr. G. C. Lloyd, Secretary of the Iron and Steel Institute, for much valuable assistance rendered in connection with the preparation of this paper.

LOW-CARBON ALLOYS OF IRON AND MANGANESE*

BY SIR ROBERT HADFIELD, BT.
(*Past-President, Iron & Steel Institute*)

(Sydney, N. S., meeting, September 9th, 1927)

CONTENTS

Section	Page
(A) PREVIOUS RESEARCH	
1. Introductory remarks regarding the author's original papers on manganese steel.....	96
Faraday's work on alloys of iron.....	97
Mushet's early experiments.....	97
2. Manganese and ferro-manganese.....	100
The early work of the Terre Noire investigators.....	101
3. Other workers: Guillet, Arnold, Burgess, Aston, Kasé, Strauss.	107
(B) THE PRESENT RESEARCH	
4. Objects of the present research.....	111
5. Production of the iron-manganese alloys for this research.....	118
(a) Cast material.....	120
(b) Forged material.....	120
(c) Heat treatment.....	120
6. Mechanical qualities:	
Methods of testing employed:	
(a) Cast material.....	121
(b) Forged material.....	121
Mechanical qualities.....	122
7. Comparison of the mechanical qualities obtained by the author with those of other investigators.....	126
8. Magnetic and electrical qualities.....	137
Specific magnetism.....	141
Electrical resistance.....	144
9. Critical ranges on heating and cooling.....	145
10. Photomicrographs.....	153
11. Corrodibility.....	156
12. Discussion of the results.....	158
13. Conclusion.....	160

*This paper was presented at the Annual Meeting of the Iron & Steel Institute, May 5th-6th, 1927.

LIST OF TABLES

	Page
I. Analyses of steels made by the Terre Noire Company and containing varying percentages of manganese up to about 2.50 per cent.....	103
II. Tensile tests on the rolled and forged steels made by the Terre Noire Company.....	104
III. Compression tests on the rolled and forged steels made by the Terre Noire Co.....	105
IV. Key table, giving the carbon and manganese percentages of the specimens prepared for this research.....	113
V. Iron-manganese alloys, varying from 0.06 to 38.90 per cent manganese. Cast material. Transverse, bending, Brinell hardness, hammer-hardening qualities.....	115-7
VI. Iron-manganese alloys, varying from 0.06 to 38.90 per cent manganese. Forged material. Tensile, shock, bending, Brinell hardness, and hammer-hardening qualities. (At end of paper).	
VII. Iron-manganese alloy, with about 83 per cent manganese. Cast material. Various hardness and toughness tests, also magnetic quality with effect of heat treatment....	124
VIII. Physical properties of iron-manganese alloys containing about 83 per cent manganese with varying carbon.....	125
IX. Iron-manganese alloys, varying from 0.43 to 33.48 per cent manganese.....	128-9
Data obtained by L. Guillet. Forged material. Tensile, shock, and Brinell hardness in the conditions— (a) as forged, (b) water-quenched.	
X. Iron-manganese alloys, varying from 1.10 to 30.60 per cent manganese.....	130
Data obtained by Professor Arnold. Forged material. Tensile qualities in the condition as annealed.	
XI. Iron-manganese alloys, varying from 1.10 to 19.85 per cent manganese.....	134
Forged material. Shock and Brinell hardness tests by the author on alloys made and supplied by Professor Arnold in the water-quenched condition.	
XII. Iron-manganese alloys, varying from 2.00 to 40.00 per cent manganese.....	135
Data obtained by T. Kasé. Cast material. Scleroscope hardness in the conditions—(a) as cast, (b) annealed.	
XIII. Comparison of the specific magnetism of iron-manganese alloys containing (a) low carbon and (b) carbon about 1 per cent in their condition as water-quenched.....	138
XIV. Iron-manganese alloys, varying from 0.03 to 15.20 per cent manganese. Magnetic qualities of the forged and annealed material.....	139
XV. Iron-manganese alloys, varying from 0.50 to 15.20 per cent manganese. Electrical resistance of the rolled material in the conditions—(a) as rolled, (b) annealed.....	144
XVI. Iron-manganese alloys, varying from 0.06 to 38.90 per cent manganese. Forged material. Electrical resistance in the condition as water-quenched, also specific magnetism in various physical conditions.....	146
XVII. Iron-manganese alloys, varying from 1.68 to 38.90 per cent manganese. Microstructure of forged material.....	154
XVIII. Iron-manganese alloys, varying from 3.95 to 38.90 per cent manganese. Corrosion in various media.....	157

LIST OF FIGURES

(For Figures, see end of paper)

Figure

1. Cast material. Transverse tests—(a) As cast, (b) water-quenched.
2. Cast material. Brinell hardness—(a) As cast, (b) annealed, (c) water-quenched.
3. Forged material. Tensile tests—(a) As forged.
4. Forged material. Tensile tests—(b) Annealed.
5. Forged material. Tensile tests—(c) Water-quenched.
6. Forged material. Shock tests—(a) As forged, (b) annealed, (c) water-quenched.
7. Forged material. Brinell hardness—(a) As forged, (b) annealed, (c) water-quenched.
8. Comparison of tensile qualities as obtained by (i) Guillet, (ii) the author in the 'as forged' condition.
9. Comparison of tensile qualities as obtained by (i) Guillet, (ii) the author in the 'as forged and water-quenched' condition.
10. Comparison of shock qualities as obtained by (i) Guillet, (ii) the author in the 'as forged' condition.
11. Comparison of shock qualities as obtained by (i) Guillet, (ii) the author in the 'as forged and water-quenched' condition.
12. Comparison of tensile qualities as obtained by (i) Arnold, (ii) the author in the 'as forged and annealed' condition.
13. Comparison of shock qualities shown by (i) Arnold alloys, (ii) the author's alloys in the 'as forged and water-quenched' condition.
14. Comparison of hardness as obtained by (i) Kasé, (ii) the author in the 'as cast' and 'as cast and annealed' conditions.
15. Forged material. Electrical resistance and specific magnetism.
16. Heating curves.
17. Cooling curves.
- 18–21. Photomicrographs of the alloys in the 'as forged' condition.
- 22–25. Photomicrographs of the alloys in the forged and water-quenched condition from 1.68 to 9.45 per cent manganese.
- 26–29. Photomicrographs of the alloys in the forged and water-quenched condition from 14.3 to 38.9 per cent manganese.

(A) PREVIOUS RESEARCH

Section 1.—Introductory Remarks regarding the Author's Original Papers on Manganese Steel

It was in 1888, and therefore now thirty-nine years since the author communicated his first two papers to the Institution of Civil Engineers entitled "Manganese Steel" and "Some Newly Discovered Properties of Alloys of Iron and Manganese," submitted at the end of the year 1887 and read before the Institution in February, 1888. These were followed by his paper "Manganese Steel", read in the same year before the Iron and Steel Institute, and in 1893 he presented a paper to the American Institute of Mining Engineers at Chicago on "Iron Alloys, with Special Reference to Manganese Steel."

These papers described the discovery and invention by the author of the steel known as manganese steel, which is now accepted as meaning specifically an alloy containing about 12 to 14 per cent manganese, 1 to $1\frac{1}{4}$ per cent carbon, and the balance iron, about 85 per cent. This valuable product represented not only the discovery of a new steel, but was practically the beginning of the important modern era of alloy steels, comprising those of the binary, ternary and quaternary types.

The author followed up his original researches referred to by similar investigations on alloys of iron with silicon, aluminium, nickel, chromium, tungsten, cobalt, molybdenum, and other elements. These were described in his various papers read, between the years 1889 and 1915, before the Institution of Civil Engineers, the Iron and Steel Institute, and other scientific and technical bodies.

The former researches of the author, however, did not cover alloys of iron and manganese low in carbon or in which carbon was almost entirely absent, a description of which is the chief object of this present paper.

Quite apart from the account of the research now presented, another paper by the author at this meeting, entitled "Manganese, the Ores and the Metal; with an Account

of the History and Production of Ferro-Manganese”, further shows the vital importance to the world of the ferrous alloys now chiefly used and known as ferro-manganese.

Faraday's work on alloys of iron.—Before the presentation in 1888 of the papers previously mentioned, comparatively little had been done with regard to alloy steels, that is, steels containing considerable percentages of elements other than iron.

It is true that Faraday devoted some of his time and energy to their study, and in 1821, in one of his publications, reference was made to alloys of iron with other elements. In carrying out some of these researches there was associated with him Dr. James Stodart, an investigator and chemist of repute, as he became a Fellow of the Royal Society in 1821, of which body Faraday was elected a Fellow in 1824. These researches were published some time afterwards, and were described in Faraday's book, “Experimental Researches in Chemistry and Physics; including a Paper by Stodart and Faraday entitled ‘Experiments on Alloys of Steel’ ” (London, 1859). At that time, however, metallurgical and chemical knowledge was very imperfect, and many of the requisite metals and alloys, today so readily procured, were then either unobtainable or obtained only with the greatest difficulty—in fact, in the main they were only available as rarities in laboratory production. It was not to be expected, therefore, that Faraday could have produced alloys which only became possible half a century later. Nevertheless, in these early experiments of his he showed the scientific foresight which so marked his career.

Some idea of the difficulties under which Faraday worked may be gleaned from a statement he made in 1822 that, as he could not go to Sheffield, he carefully prepared the mixtures for his alloy in London and sent these by coach under the care of an assistant, who was to witness the processes of manufacture, including melting, forging, and rolling, at Messrs. Sanderson's Works, which still exist in that city.

Mushet's early experiments.—Much later there were also the Mushets, father and son, David and Robert, to whom great credit should be given, as they evolved, more than half a century ago, alloy steels containing tungsten which

were used for cutting tools; but owing to the high percentages of carbon present these steels were exceedingly brittle and only useful for the particular application mentioned.

In 1884 the author had an interesting correspondence regarding iron-manganese alloys with the late Robert Mushet; some of this appeared in the technical journal then known as *Iron*. In June 1884 Mr. Mushet was kind enough to write as follows: "My remarks in *Iron* had reference to steel proper, such as existed before the age of cheap steel and its creators came upon the scene. In your patent your claim is really not for steel at all, but for an alloy in certain proportions of iron and metallic manganese, containing also carbon, but as little of that as you can help. Your alloy likewise possessing some of the properties of steel, being, in fact, to a certain extent, a substitute for steel, just as brass. Do you see, then, that I have not protested against your steel, but only against adding metallic manganese to steel produced on the old system. I have also no desire to prejudice anyone as regards your patent, and should regret that anything I had written should have such an effect."

It is interesting to note that Robert Mushet expressed the opinion that he did not regard the author's manganese steel as a steel at all, and in one sense he was correct, because manganese steel when quenched from a high temperature is not hardened like high-carbon steel, but is toughened. On the other hand, in this present age of alloys of iron with other elements, the word 'steel' is accepted as a useful generic title, indicating the difference between cast and wrought iron as compared with 'steel'.

In this respect the author quotes the interesting statement made in 1903 by the late Professor Floris Osmond, one of the great leaders of the past in the development of modern metallurgical thought and its application to science. This is quoted in full because of the stimulation it should give to our rising generation of metallurgists, and also as showing how he, Osmond, viewed the advance of thought brought about by the important development in question. The following were his words: "The series of the Hadfield alloys had been prepared with a degree of technical skill which upset many falsely conceived ideas, resulting from imperfect

preparation or from faulty manipulation. Hadfield's method was a truly scientific one, by means of which all the independent variables which could be disposed of were eliminated. With the materials for investigation thus prepared, which for a long time had been unrivalled, the results obtained were at once clear, coherent, and definite. Moreover, Hadfield had not only made the best personal use of this wealth of material, but with never-failing generosity, of which the writer had many times availed himself, he had placed it at the disposal of those inventors who were desirous of subjecting it to their methods and using it for their researches. Consequently, the useful results had rapidly gone on increasing, and from the accumulation of these the general laws had been evolved which formed the main object of all research."

Again, when, on the same occasion, speaking of the transformations of iron and steel, Osmond made the following important pronouncement, which is really a metallurgical landmark: "Now, according as, with a given addition of one or several foreign bodies, and under fixed conditions of heating and cooling, the transformations were maintained above 400° C. approximately, or were lowered so as to occur between 400° C. and the ordinary temperature, or were pushed down to a point below the ordinary temperature, there would be produced three essential types of iron, not taking account of the intermediary types which connected them. These three types would correspond respectively to the complete transformations, to the incomplete transformations, and to no transformations at all. The first type was soft iron. The second corresponded to hard, quenched steel and its kindred alloys. The third corresponded to non-magnetic steels, which are malleable and at the same time very difficult to work by forging. The first two had been familiar since the dawn of history, the third was due to the discoveries of Hadfield. Considered from this point of view, the discovery of manganese steel was not, therefore, a discovery only of a new alloy, curious and yet useful, but it ranked as a discovery equal in importance only to that of the effect of quenching, that is, the hardening of steel by quenching, in the history of the metallurgy of iron, the only one of the same order which it had been reserved for our age to make."

Section 2.—Manganese and Ferro-Manganese

It was the metal manganese in its combination known as ferro-manganese which led to the discovery of the useful product manganese steel. So long as there was only available the material then, and still, termed *spiegel*, an alloy containing comparatively little manganese, up to, say, between 20 and 30 per cent, and high percentages of carbon, the discovery and invention of 'manganese steel' could not have been made. Such an alloy of iron, if made with *spiegel*, would not have had any industrial application, the carbon present being too high. The resulting product would have been a species of white cast iron, not malleable or forgeable, and of exceedingly brittle nature, remaining so no matter what might have been the heat treatment employed.

These materials are fully described in the author's other paper entitled "Manganese, the Ores and the Metal; with an account of the History and Production of Ferro-Manganese".

At the time of the author's early experiments resulting in the discovery of manganese steel, manganese was only just beginning to be available in the form of rich ferro-manganese containing 60 to 80 per cent of manganese, also in the high manganese-silicon alloy known as *silico-spiegel*. The production of these ferro-alloys in the blast-furnace, nearly fifty years ago, bearing all the circumstances of the time in mind, was in itself a great achievement, and the highest credit is due to those who were responsible for their successful manufacture and introduction. Full reference will be made to these investigators later.

Continuing the history of the steel alloys, there appeared in *Iron* of April 18th, 1884, under the heading of "The Creators of the Age of Steel," a letter signed by Robert Mushet, Cheltenham, in which he stated that he believed the first man who made what we now term ferro-manganese was his father, David Mushet, as shown in his book, "Papers on Iron and Steel, Practical and Experimental" (London, 1840). These experiments were made in clay crucibles, but were repeated years afterwards in graphite pots, when more than double the percentage of manganese metal previously obtained was reduced from the ore.

In this book, Part II, Chapter XV, p. 773, entitled "On Cast Iron and Steel: Experiments to ascertain whether Manganese may be Alloyed with Iron," David Mushet made the following statement: "The alloy now obtained will be composed of iron 71.4; metallic manganese, 28.6; total, 100 parts." It is probable that the percentage of manganese was not directly estimated, though from the fact that it was afterwards discovered to be non-magnetic there is no doubt the percentage of manganese present was quite considerable, and that the alloy could have been well described as a ferro-manganese product.

Mr. Mushet added the following with regard to his experiments: "I was now satisfied that ores of manganese might be smelted with success along with our common argillaceous ironstone in the blast-furnace, with a considerable augmentation of metallic product; and much pleased to have discovered the fact that iron alloyed with manganese, in certain proportions, ceases to be obedient to the magnet. This fact alone renders it extremely probable that the presence of manganese is not essential to the formation of good steel; and that those irons analysed by Bergman contain no notable quantity, seeing that the strongest and most durable magnets are made of steel manufactured from such iron."

The Early Work of the Terre Noire Investigators.—Coming down to later times the author of this paper desires to emphasise the importance of the early work in this branch of metallurgy carried out by the Terre Noire Company, through its able directors, MM. Euverte and Gautier, also M. Alexandre Pourcel, who is happily still with us and one of our Honorary Vice-Presidents.

When visiting the Paris Universal Exhibition in 1878, at which time the author was nineteen years of age, the Terre Noire Company gave him a copy of their most interesting pamphlet, entitled "Terre Noire, La Voulte and Bessèges, Foundry and Ironworks Company: History and Statistics of the Company, Catalogue of Exhibits and Other Information," covering some sixty pages. The whole of this, with the useful tables of tests, the author translated into English. It was

the carrying out of this translation which doubtless helped largely to influence and turn his mind into the channel of the study of alloys of iron with other elements.

The history of this company is a fascinating one of metallurgical enterprise, but the author cannot do more here than refer to their work in connection with the use of manganese steel, although in the author's accompanying paper on ferro-manganese, special reference is naturally made to the work they accomplished in the production of manganese alloys. In 1868 this company, which, having at first been concerned only with the production of cast iron and ordinary irons, had a few years previously taken up the manufacture of steel, began the manufacture of extra soft steels, thanks to the aid of what they then termed 'rich manganese alloys', the initiation and manufacture of which on an industrial scale were rightly claimed by them.

In 1875, again by the aid of manganese alloys, the company introduced and worked for a short time a method of using old materials, such as rails containing small amounts of phosphorus, for working up into steel rails, provided the carbon present was not too high. In this same year the manufacture of ferro-manganese made further strides, and alloys were obtained in the blast-furnace containing 80 per cent manganese.

From 1870 to 1880 the Terre Noire Company made a series of experiments which led to their being among the first to carry out the practical and everyday manufacture of cast steel without blowholes, destined to render such great service to industry. This manufacture necessitated the employment of siliceous pig-irons, which were obtained in their own blast-furnaces, also the alloy known as silico-spiegel, containing iron, silicon, and manganese.

A series of tests was carried out upon rolled and hammered steel containing different percentages of manganese, commencing with 0.52 and rising to 2.45 per cent, but nothing higher. Similar tests were carried out on treated and untreated material.

A superb collection of specimens representing these various experiments and other researches was exhibited by the Terre Noire Company at the Paris Exhibition of 1878.

Included in this collection were five specimens containing from 0.45 to 0.59 per cent carbon, about 0.03 to 0.069 each of sulphur and phosphorus, with manganese varying as follows: 0.52, 1.06, 1.30, 2.00, and 2.45 per cent. The research showed that on adding 2.45 per cent manganese a brittle and comparatively useless product was obtained, so those conducting the experiments did not pursue them in the direction afterwards followed by the author, which ultimately led to the discovery of manganese steel.

In view of the importance of this subject, the author thought that, from the historical point of view, it would be interesting to add here an extract from the translation made by him from the original pamphlet of the Terre Noire Company, describing their exhibits and relating in particular to the effect of manganese. This information has not, to his knowledge, been published before in any technical proceedings, and presents valuable data with regard to rolled and forged steel containing small quantities of manganese, also showing the type of experiments and tests carried out at that time. Full particulars are there given of the composition and mechanical tests, including tensile and compression tests on the steel, both in its untreated and oil-tempered conditions. Bending and drop-tup tests were also carried out, but the tables of results of these are omitted here from consideration of space.

The following Tables, I to III, and accompanying description set forth the information given in the pamphlet before referred to.

In Table I is given the analysis of each of the five casts in this series.

Table I.—Rolled and Forged Steel containing Different Quantities of Manganese (Terre-Noire, 1878).

	Carbon Per cent	Silicon Per cent	Sulphur Per cent	Phosphorus Per cent	Manganese Per cent
Cast No. 26..	0.0450	traces	traces	0.067	0.521
Cast No. 33..	0.467	"	"	0.072	1.060
Cast No. 30..	0.515	"	"	0.061	1.305
Cast No. 21..	0.560	"	"	0.058	2.008
Cast No. 17..	0.599	"	"	0.072	2.458

Table II.—Tensile Tests upon Rolled and Forged Steel containing
Different Quantities of Manganese (Terre-Noire, 1878).

Number of cast:.....	26	33	30	21	
Manganese (per cent):.....	0.521	1.060	1.305	2.008	
(A) Untreated					
Test-bars ½ inch (full) diameter by 3 15/16 inch in length	Tons	Tons	Tons	Tons	
Limit of elasticity. Load per square inch.....	17	23	28	31	
Breaking { Upon original stress per area.....	34	41	52	57	
square { Upon fractured inch area.....	61	71	85	74	
Percentage of elongation....	24.2	21.0	15.7	9.5	
Test-bars ¾ inch diameter by 7 7/8 inch in length	Tons	Tons	Tons	Tons	
Limit of elasticity. Load per square inch.....	17	20	26	30	
Breaking { Upon original stress per area.....	33	39	49	56	
square { Upon fractured inch..... area.....	62	74	89	83	
Percentage of elonga- tion	Measured over 7 7/8 inch....	24.5	21.4	17.4	10.5
	Measured over 3 15/16 inch.	29.75	27.5	21.25	12.0
(B) Oil-Tempered					
Test bars ½ inch (full) diameter by 3 15/16 inch in length	Tons	Tons	Tons	Tons	
Limit of elasticity. Load per square inch.....	31	44	..	..
Breaking { Upon original stress per area.....	48	83	Cracked in tem- pering	Cracked in tempering	
square { Upon fractured inch area.....	89	Test-bar broken at the mark			
Percentage of elongation....	14.0				
Test-bars ¾ inch diameter by 7 7/8 inch in length	Tons	Tons	Tons	Tons	
Limit of elasticity. Load per square inch.....	26	41	..	..
Breaking { Upon original stress per area.....	49	63	Cracked in tem- pering	Cracked in tempering	
square { Upon fractured inch area.....	82	Test-bar broken at the collar			
Percentage of elonga- tion	Measured over 7 7/8 inch....				12.0
	Measured over 3 15/16 inch.	16.0			

In this pamphlet the following statement is made:

"The different specimens belonging to this series are to be found in the following order amongst the exhibits on our (Terre Noire) stand:

"*Cast No. 26, containing 0.52 per cent manganese.*—Twenty-one specimens of bars submitted to drop, tensile, and compressive tests. Similar in diameter and length to those of the carbon series.

"*Cast No. 33, containing 1.06 per cent manganese.*—Twenty specimens of tested bars, same size, etc., as above.

"*Cast No. 30, containing 1.31 per cent manganese.*—Sixteen specimens of tested bars, same size, etc., as above.

"*Cast No. 21, containing 2.01 per cent manganese.*—Nine specimens of tested bars, same size, etc., as above.

"*Cast No. 17, containing 2.46 per cent manganese.*—Two specimens. A fracture from an unforged ingot and a rolled bar. The metal from No. 17 cast was exceptionally hard, and the steel being so difficult to work it was found impossible to forge or roll sufficient bars for testing.

"The same tests were made with this manganese steel as with the carbon steel. The conditions of the tests were identical."

Table III.—Compression Tests upon Rolled and Forged Steel containing Different Quantities of Manganese (Terre-Noire, 1878).

Number of cast:.....	26	33	30
Manganese (per cent):.....	0.521	1.060	1.305
(A) Untreated			
Load supported by the compressed cylinders (tons).....	32	32	32
Height before compression (inch).....	25/64	25/64	13/32
Height after compression (inch).....	9/64	5/32	11/64
(B) Oil-Tempered			
Load supported by the compressed cylinders (tons).....	32	32	32
Height before compression (inch).....	25/64	25/64	25/64
Height after compression (inch).....	3/16	3/16	13/64
The cylinders above tested were 13/32 inch in diameter			

As showing that the Terre Noire Company did not regard their experiments, recorded *in extenso* above, as in any way anticipating the author's discovery of manganese steel, he would like to quote the following letter addressed to him in September, 1884, by Mr. Ferdinand Gautier of the Terre Noire Company:

"I thank you very much for your beautiful sample of manganese steel. After carefully examining and inspecting the fracture and other tests, I feel bound to state that this manganese steel is an entirely new kind of steel and is a new invention. Such steel has never previously been manufactured. In fact, this manganese steel could not now or previously have been made except for the introduction by myself and others of high percentages of ferro-manganese containing 60 to 84 per cent of metallic manganese. These high percentages of ferro-manganese have been and could only be made during the last few years."

As the author has said earlier in this section, these remarks were quite correct, and great credit was due to the Terre Noire Company for helping to solve the difficulties of manufacturing cheaply the alloy known as ferro-manganese, from which the world is today benefiting so largely. When, during the war, ferro-manganese ran short, much inferior steel had to be made for want of these products. This is dealt with more fully in Section (A)5 of the author's other paper now presented.

In the same way, the author's friend of long standing, the late M. H. Brustlein, of MM. Jacob Holtzer, Unieux, who did so much to further the development of alloys of iron and chromium, also admitted that, whilst he had experimented on alloys of iron and manganese, he had not exceeded, in these alloys, more than about 7 per cent of manganese, whereas in order to obtain the characteristic physical qualities of manganese steel the presence of at least 11 per cent and up to about 14 per cent of the metal manganese is necessary.

Mr. Alexandre Pourcel was likewise kind enough to state in 1888 that he considered the production of manganese steel the most important event in practical metallurgy during

the preceding ten years. There is no doubt that the discovery and invention of manganese steel opened up a vast new field for research.

The importance of Mr. Pourcel's work has been well described in the excellent monograph, prepared in April, 1925, by Mr. G. Magniny, of the Fonderies, Forges et Aciéries de Saint-Etienne, in connection with the pleasing ceremonies on the occasion of the sixtieth anniversary of Mr. Pourcel's entrance into industry.

In consequence of the valuable communications made by him to the Société de l'Industrie Minérale, Mr. Pourcel was elected to a seat on its Council, which position he occupied until his departure for Spain in 1883, and on the occasion of his cinquantenaire that Society presented to him its Medal of Honour to mark its appreciation of his great services to metallurgy. As a further mark of the great esteem in which he is held, the Iron and Steel Institute in 1909 conferred upon him the highest distinction within its power, by presenting to him the Bessemer Gold Medal, the blue ribbon of metallurgy, and in 1918 he was elected an Honorary Vice-President of the Institute.

*Section 3.—Other Workers: Guillet, Arnold, Burgess,
Aston, Kasé, and Strauss*

Following the author's early published researches on alloy steels, many other investigators entered the field, but the author will only refer to those who have worked with the subject of this present paper, namely, alloys of iron and manganese. There were notable contributions by Guillet and Arnold, also Burgess and Aston, and more recently by Kasé, a Japanese research worker in Professor Honda's laboratory, and Dr. Jerome Strauss.

The experiments by Dr. L. Guillet formed a complete series up to as high as 33.50 per cent manganese. These were described by him in communications to *Revue de Métallurgie*, La Société d'Encouragement pour l'Industrie Nationale, and other societies, also in his book "Les Aciers Spéciaux," published in 1904. In this series the carbon varied from

0.034 to 0.396 per cent. In several cases there was also the disturbing influence of considerable percentages of silicon, this element being present in varying amounts up to a maximum of 1.36 per cent. On the other hand, the sulphur and phosphorus were regarded as being exceedingly low, as shown in Table IX.

In passing, and as an interesting personal reminiscence of the author's early work, he would like to mention that in filing away some papers recently he came across a letter dated June, 1904, from his friend Dr. Guillet, who had just sent him a copy of his (Guillet's) book, "*Les Aciers Spéciaux*." These were his words: "In sending you this first volume on 'Special Steels' I beg, dear Master, to thank you for the advice you have given me and the encouragement which you have been kind enough to show me at all times. It is to your own work—known and admired throughout the whole world—that I owe the ability to have added in a few months a modest contribution to the knowledge of special steels which you were the first to study. I beg you, therefore, to accept this work as proof of profound and respectful admiration."

The experiments of Professor Arnold, made in 1906–1911, covered a series of iron-manganese alloys from about 0.3 up to about 35.0 per cent of manganese and low in carbon. At the same time, another series of alloys with varying manganese was prepared by him, each containing about 0.85 per cent carbon. The research on these was apparently, however, only carried out to a limited extent, the results of which will be found in a series of papers read before the Iron and Steel Institute.

The preparation of the whole series of alloys was described by Arnold and Knowles in 1906 in a "Preliminary Note on the Influence of Manganese on Iron." Later, in 1910, the mechanical qualities of the alloys containing about 30 per cent manganese were given separately in a paper by Arnold on "Uniform Nomenclature of Iron and Steel," followed in 1911 by those of the alloys containing up to about 20 per

cent manganese in the paper by Arnold and Knowles entitled "The Mechanical Influence of Carbon on Alloys of Iron and Manganese."

The data given in these researches, whilst useful, are only scanty and do not give the desired information, conveyed by the series of steels, with their accompanying physical tests of all kinds, presented in this paper.

Professors C. F. Burgess and J. Aston, of the University of Wisconsin, in two papers entitled "Observations upon the Alloys of Iron and Manganese," published in *Electrochemical and Metallurgical Industry*, in November, 1909, also "The Electrical Resistance of Iron Alloys," read at the Twentieth General Meeting of the American Electrochemical Society, September, 1911, published the results of their magnetic and electrical tests upon a series of iron-manganese alloys which they had prepared. These alloys, ten in number, and covering a range from 0.505 to 10.419 per cent manganese, formed one of several series of alloys of iron with other elements, comprising a total of 263 different alloys from seventeen different added elements. The iron used as a base for all these materials was electrolytic iron, and the alloys were melted in a covered magnesia-lined graphite crucible, bedded in an electric resistance furnace. The ingot, about 1 lb. in weight, was then forged into a rod under a steam-hammer. It is not stated in what form the manganese was introduced into the iron-manganese alloys, but presumably as metallic manganese of a high percentage.

Except for the determination of the manganese percentage in three of the ten alloys, no analyses of the specimens were made, the authors apparently relying in general upon their calculated compositions as determined by the mixtures used, and on their having taken every precaution to avoid contamination. It cannot, therefore, be regarded as certain that the alloys did not contain elements other than manganese in sufficient proportions to influence their characteristics.

The magnetic and electrical data obtained by these investigators are referred to in Section 8. Tensile tests were also made by these investigators on three of their alloys of different percentages, and are referred to in Section 7 of the present paper.

The research by the Japanese investigator, Mr. T. Kasé, under the direction of Professor K. Honda, "On the Structural Diagrams of Some Special Steels," was published in the *Science Reports of the Tôhoku Imperial University*, Series I., Vol. XVI, No. 4. It comprised the preparation of three separate series of alloys of iron with chromium, nickel, and manganese respectively.

The alloys with manganese included specimens in which the carbon content was kept as low as possible, and also others with carbon added to the amount of 0.8 and 4.3 per cent respectively. The series with low carbon comprised twelve specimens with increasing amounts of manganese up to 60 per cent.

The value of this research was to some extent limited by the extremely small amount of material prepared, only 30 grammes in weight of each alloy, from which the tests described were taken. Notwithstanding the limitations thus imposed the examination made was thorough, comprising, in addition to chemical analysis in certain cases, hardness tests by means of the scleroscope, a thermo-magnetic and dilatometric analysis of the type familiarised by Professor Honda, also an examination of the microstructure.

The specimens were prepared by melting a mixture of iron and metallic manganese in the necessary proportions in an electric furnace *in vacuo*, and besides an examination in their condition as found after being allowed to cool in the melting furnace, tests were also taken after their immersion in liquid air, then after annealing at 800° to 900°C., according to composition, *in vacuo*, and finally after again immersing them in liquid air. All the tests referred to materials in the cast form, no forged specimens having been prepared.

A comparison of the results thus obtained by Kasé and those by the author, so far as this is possible, is made later in the present paper when discussing the results of the mechanical and other tests.

Dr. Jerome Strauss, of the United States Naval Gun Factory, Washington, a well-known writer on metallurgical subjects, published in 1923 a paper on "Characteristics of some Manganese Steels" ⁽¹⁾.

⁽¹⁾ *Transactions of the American Society for Steel Treating*, December 1923. pp. 665-7.8.

In this paper he discussed generally the use of manganese as a constituent of steel, and presented the results of the examination of a specially prepared series of iron-manganese alloys with manganese content from 1.85 to 16.35 per cent, and containing carbon in varying amounts from 0.03 to 1.85 per cent. This series, however, only included three alloys with low carbon, 0.03 to 0.05 per cent, and with manganese 5.88, 8.61, and 16.35 per cent respectively, the silicon percentage being kept low.

The whole of the alloys were prepared from a charge made up from iron of a pure quality, crucible melted carbon tool steel, carbon-free manganese, high-grade 80 per cent ferro-manganese and, when carbon was required to be added, washed metal, in the necessary proportions. The melting was accomplished in an Ajax-Northrup high-frequency furnace in an open crucible, and each material cast into a small ingot about $1\frac{1}{4}$ inch square and 7 inches long.

The research was directed towards ascertaining the microstructure of iron-carbon-manganese steels, and its relationship to their mechanical properties, and for this purpose observations of the microstructure and Brinell hardness were made on both the cast and forged materials, while tensile tests were carried out on the forged material. In addition to the untreated material examination was made after annealing, quenching in oil or water, with also in some cases a quenching and tempering treatment.

From the point of view of the present paper, the small number of the alloys low in carbon rather limits the interest of this particular research. It so happens, however, that one of the alloys prepared by Dr. Jerome Strauss provides additional and independent evidence regarding the qualities obtained with a particular percentage of manganese, namely, about 5 per cent, as to which there is some divergence amongst investigators. This is more particularly referred to in Section 7.

(B) THE PRESENT RESEARCH

Section 4.—Objects of the Present Research

In view of the fact that the manganese steel now used industrially contains considerable percentages of carbon, varying from about 0.90 to 1.50 per cent, and that both

carbon and manganese are instrumental in producing the remarkable qualities of this alloy, the importance of ascertaining definitely the properties conferred by manganese itself upon iron, that is, in the practical absence of carbon, has always been apparent. It was from this consideration that the author himself prepared the various alloys of iron and manganese now described, some of them made many years ago, and in which the carbon was kept very low. Thus, comparison could be made between the qualities of these and of the materials represented by his earlier researches—namely, between the materials representing the two types of alloys of iron and manganese, the one with carbon varying from about 0.50 to 1.20 per cent and the other with little or no carbon, 0.08 to 0.20 per cent, while keeping these alloys, as far as practicable, free from other elements; that is, they were generally but little influenced by the presence of other elements. Some of these alloys, as regards their percentages of manganese, apart from their low carbon, would comprise products which might be considered to come under the term 'manganese steel', though they must not be confused with the latter for industrial applications, for which there seems to be no particular field in the case of these low-carbon alloys. Nevertheless, it is important, from the scientific point of view, to have their various qualities—chemical, physical, and mechanical—put on record.

As already stated, a certain portion of the research work now presented was carried out some time ago, but owing to the stress of war and subsequent reorganisation to peace work it was not possible to complete the research until quite recently. It was in the expectation of being able to complete the full series of tests at an earlier date that the author decided to postpone publication of the earlier tests; moreover, the results obtained did not seem to indicate that such iron-manganese alloys presented qualities likely to be of immediate practical value.

The author's series of alloys comprises specimens showing the influence of manganese from 0.06 to 38.90 per cent, carbon not exceeding on the average 0.08 per cent. In respect of the desirability in such a series of alloys of keeping elements

other than manganese, specially carbon and silicon, down to the lowest possible point, the present series best meets this requirement, as shown by the following figures:

In the Guillet set of specimens, the carbon varied from 0.034 to 0.396 per cent, silicon from 0.16 to 1.36 per cent, sulphur from a trace to 0.025 per cent, and phosphorus from 0.010 to 0.032 per cent. In the Hadfield set of specimens, the carbon varied from 0.06 to 0.20 per cent, silicon from 0.03 to 0.70 per cent, sulphur from 0.047 to 0.120 per cent, and phosphorus from 0.036 to 0.070 per cent.

The accompanying Table IV gives the contents in carbon and manganese of the various specimens included in the present research, from which it will be seen that the chief disturbing element, carbon, is low, and varies but little. The other elements present are of fairly normal percentages and probably have not much influence on the physical qualities of the various materials prepared as regards the unannealed and annealed conditions. Full analyses, including carbon, silicon, sulphur, phosphorus, and manganese, are given in Table VI.

Table IV.—Key Table giving the Carbon and Manganese Percentages of the Specimens prepared for this Research.

Group No.	Specimen mark	Carbon	Manganese
1	1727D	0.11	0.06
1	1379A	0.07	1.68
2	1379B	0.06	3.95
2	1379B/4	0.10	4.10
2	1379B/3	0.11	4.82
2	1379C/1	0.06	6.68
2	1379C/2	0.08	6.75
2	1379D	0.07	9.45
3	1379E	0.09	12.95
3	1379E/3	0.14	14.30
4	1379G	0.15	17.10
4	1379F	0.08	22.70
4	1379H	0.20	38.90
5	1379I	0.29	83.50

Further, in the present series the author has presented the following information which, to the best of his knowledge, has not before been determined on such a series, that is, with regard to the co-ordination of so many different physical qualities.

The various specimens were obtained in both the cast and the forged form. In each case their qualities were determined: (1) in the untreated condition, *i.e.*, as forged or as cast; (2) after annealing by heating to 860° to 890°C. and cooling very slowly; (3) as water-quenched from a high temperature. The object of the latter treatment was to see whether any toughening effect occurred as in the standard material known as the Hadfield manganese steel under such treatment, namely, when heated and water-quenched from the extraordinarily high temperatures—that is, as compared with those used for ordinary steel—of 950° to 1050°C., which, when introduced by the author in 1883, were indeed a new departure in methods of metallurgical treatment.

The tests carried out include the following: (*a*) For the cast material: bending tests on cast strips and transverse bars; also Brinell ball-hardness and hammer-hardening tests. (*b*) For the forged material: bending tests on forged strips; tensile tests showing the yield point, tenacity, elongation, and reduction in area; Frémont shock tests on specimens (*a*) nicked, (*b*) without nicks; hammer-hardening tests; Brinell ball-hardness tests.

In addition, in the case of the forged material, a complete series of the following tests was made: the specific magnetism of each of the thirteen specimens, from 1.68 to 38.90 per cent manganese; electrical resistance; heating and cooling curves; microstructure of the specimens; their corrodibility.

A number of tests have also been carried out upon the unforgeable alloy containing 83.50 per cent of manganese—that is, similar to high-percentage ferro-manganese but with quite low carbon, namely, 0.29 per cent. In this case, owing to the brittle character of the material and its non-forgeability, a similar series to that made upon the remaining materials was not possible, and the tests actually carried out were of a character more suitable to display its qualities both as cast and also as affected by heat treatment.

Table VA.—Mechanical Tests on Cast Material.
All the specimens in this section were tested in the condition 'as cast'

Group No.	Specimen mark	Analysis			Bending strip 7 in. x 1 in. x $\frac{1}{4}$ in.			Transverse bar 1 inch square, 12-inch supports				Brinell hardness		Hammer-hardening. Portion of transverse bar hammered for 15 minutes with ball end of 3-lb. hammer
		Car- bon, %	Man- ganese, %	Iron by diff., %	Angle bent Degrees	Fracture	Test No.	Break- ing load lb. per sq. in.	Angle bent, De- gree	Fracture	Trans- verse bar	Bend- ing strip	Brinell before ham- mer- ing	
1	1727D	0.11	0.06	99.52	180 unbroken	.....	B761c	5890	55	Bright crystalline and fibrous. Sound	116	122	116	168
1	1379A	0.07	1.68	98.03	77 broken	Slightly un- sound	B769c	4760	23	Fibrous, with granular spots	137	143	137	181
2	1379B	0.06	3.95	95.73	9 "	Slightly un- sound	B770c	2847	2	Crystalline	288	327	288	277 ¹
2	1379B/4	0.10	4.10	95.53	Nil	Sound	B755c	2860	1	Coarse crystalline. Sound	311	340	311	302
2	1379B/3	0.11	4.82	94.78	1 "	"	B756c	3020	1	Coarse crystalline. Sound	364	371	364	347
2	1379C/1	0.06	6.68	92.99	2 "	"	Not made				...	346	Not made	
2	1379C/2	0.08	6.75	92.95	12 "	Slightly un- sound					...	351		
2	1379D	0.07	9.45	90.24	11 "	Sound	"				...	375	"	
3	1379E	0.09	12.95	86.69	15 "	Unsound	B771c	3790	1	Crystalline. Sound	306	327	306	387 ²
3	1379E/3	0.14	14.30	85.21	5 "	Slightly un- sound	B772c	3740	2	"	256	248	256	512
4	1379G	0.15	17.10	82.29	25 "	Slightly un- sound	3706c	3890	2	Bright crystalline. Very un- sound	192	222	192	432
4	1379F	0.08	22.70	76.99	23 "	Sound	B773c	3441	5	Light grey, granular. Un- sound centre	202	228	202	392
4	1379H	0.20	38.90	60.11	50 "	"	3707c	4330	16	Bright crystalline. Sound	143	148	143	332
5	1379I	0.29	83.50	14.75	(See Table VIII)									

¹ Cracked after 7 minutes.

² Cracked after 4 minutes.

Table VB.—Mechanical Tests on Cast Material.

All the specimens in this section were tested in the condition 'as annealed'.

Group No.	Specimen mark	Analysis			Bending strip 7 in. x 1 in. x $\frac{1}{4}$ in.		Transverse bar, 1 inch square, 12-inch supports	Brinell hardness	
		Car- bon, %	Man- ganese, %	Iron (by diff.), %	Angle bent, Degrees	Fracture		Trans- verse bar	Bending strip
1	1727D	0.11	0.06	99.52	Double, unbroken	.....	No transverse bars were prepared	...	110
1	1379A	0.07	1.68	98.03	"	.....		...	143
2	1379B	0.06	3.95	95.73	4 broken	Slightly unsmooth		...	242
2	1379B/4	0.10	4.10	95.53	5 "	Sound		...	291
2	1379B/3	0.11	4.82	94.78	7 "	Slightly unsmooth		...	302
2	1379C/1	0.06	6.68	92.99	2 "	"		...	332
2	1379C/2	0.08	6.75	92.95	Nil	Sound		...	298
2	1379D	0.07	9.45	90.24	7 "	Slightly unsmooth		...	330
3	1379E	0.09	12.95	86.69	25 "	Very unsmooth		...	309
3	1379E/3	0.14	14.30	85.21	8 "	Sound		...	265
4	1379G	0.15	17.10	82.29	13 "	Slightly unsmooth		...	207
4	1379F	0.08	22.70	76.99	45 "	Sound		...	215
4	1379H	0.20	38.90	60.11	22 "	Slightly unsmooth		...	132
5	1379I	0.29	83.50	14.75		(See Table VIII)		...	

Table Vc.—Mechanical Tests on Cast Material.

All the specimens in this section were tested in the condition 'as water-quenched'.

Group No.	Specimen mark	Analysis			Bending strip. 7 in. x 1 in x 3/4 in.		Transverse bar 1 inch square, 12-inch supports					Brinell hardness		Hammer-hardening Portion of transverse bar hammered for 15 minutes with ball end of 3-lb. hammer
		Carbon %	Man-ganese %	Iron (by diff) %	Angle bent. Degrees	Fracture	Test No.	Break-ing load. Lb. per sq. in.	Angle bent. Degrees	Fracture	Trans-verse bar	Bend-ing strip		
1	1727D	0.11	0.06	99.52	180 unbroken	Sound	B762c	7260	180	Granular.	126	151	185	
1	1379A	0.07	1.68	98.03	Slightly cracked	Unsound	3708c	5400	8	Granular. Unsound	131	179	229	
2	1379B	0.06	3.95	95.73	16 broken	Very un-sound	3709c	7180	1	Fine crystalline. Unsound	324	262	317	
2	1379B/4	0.10	4.10	95.53	5 "	Sound	B763c	6640	1	Fine grey crystalline Sound	362	381	418	
2	1379B/3	0.11	4.82	94.78	2 "	"	B764c	9350	1	Very fine grey. Sound	359	388	387	
2	1379C/1	0.06	6.68	92.99	4 "	"	3710c	2040	1	Bright crystalline. Unsound	364	367	454	
2	1379C/2	0.08	6.75	92.95	No strip	.....				Not made	Not made		Not made
2	1379D	0.07	9.45	90.24	5 broken	Sound	3711c	1620	1	Silvery crystalline. Unsound centre	369	381	Too un-sound to test	
3	1379E	0.09	12.95	86.69	15 "	Slightly unsound	3712c	2480	1	Crystalline. Badly honeycombed	439	327	423	
3	1379E/3	0.14	14.30	83.21	10 "	Sound	.....	5250	10	Radial crystalline. Sound	283	282	495
4	1379G	0.15	17.10	82.29	40 "	Unsound	3713c	4260	9	Bright crystalline. Very unsound	212	208	471	
4	1379F	0.08	22.70	76.99	41 "	Slightly unsound	3714c	4600	9	Crystalline. Sound	197	222	439	
4	1379H	0.20	38.90	60.11	Double, un-broken	.....	3715c	8450	103	Coarse, granular crystalline edge	154	159	346
5	1379I	0.29	83.50	14.75		(See Table VIII)								

(See Table VIII)

The author also calls attention to the important work in the same direction now being carried out by Dr. W. Rosenhain, assisted by Dr. Marie Gayler and others, at the National Physical Laboratory, on an extremely pure series of iron-manganese alloys melted *in vacuo*, and including an investigation of their mechanical and physical qualities. The work so far carried out in the production of these alloys is described in the Reports of the National Physical Laboratory for the years 1924, 1925, and 1926. When the series is completed with physical and other tests, it will be interesting to compare the results obtained with those made on a manufacturing scale and described in this paper.

*Section 5.—Production of the Iron-Manganese Alloys
for this Research*

The production of this series of alloys has extended over a considerable range of time, some of them being made before the war when the purer types of manganese metal now available and comparatively low in sulphur could not be obtained, yet the results have been most useful. The series comprises the alloys A, B, C₁, C₂, D, E, and F, ranging from about 1.7 per cent to about 23 per cent of manganese. Later were added alloys G and H, extending the range up to about 39 per cent of manganese.

For the purpose of comparison, a low-carbon steel, No. 1727 D, prepared in a similar manner, but containing practically no manganese, was also included.

There are also several duplicates of alloys in the original series. These contained lower percentages of metalloids and were prepared with a view to the confirmation or otherwise of certain characteristics noted in the first series made some time ago. Details of these are given and explained later, in Section 7.

A further alloy, No. 1379 I, containing about 83 per cent manganese, was also prepared at this later period. The qualities of ferro-manganese of this percentage and containing about 7 per cent of carbon were fairly well known, and it was thought interesting to ascertain the qualities of such an

alloy, that is, with about 80 per cent of manganese, with practical absence of carbon, as more or less representative of the characteristics to be found at the higher end of the iron-manganese series.

In the preparation of each of these alloys the same general procedure was adopted throughout, namely, the addition of manganese metal containing the highest available percentage of manganese and as free as possible from other elements, to molten iron as free as possible from carbon and silicon. Aluminium to the amount of $1\frac{1}{4}$ to $1\frac{1}{2}$ ounces in a 50 to 60 lb. quantity of the alloy was added to ensure soundness. The method was also adopted of heating the metallic manganese to redness in the crucible into which the molten iron, free from carbon, was afterwards poured. Naturally, for this purpose the well-known chemical activity of manganese with a silica lining demanded the use of a basic-lined crucible.

The analyses of the metallic manganese employed were as follows:

	Carbon %	Silicon %	Manganese %
For the original series of alloys.....	0.18	2.95	92.17
For the later alloys, B/3, B/4, E/3, G, H, I.....	0.08	1.40	95.30

The analyses given in Table VI show that the author's experiments to produce alloys of iron and manganese, with but little disturbing effects of other elements, were on the whole successful. Carbon was not present to more than the amount of 0.20 per cent, even in the alloy containing 39 per cent manganese, and reaching the still comparatively small figure of 0.29 per cent in the 83 per cent alloy. Silicon was the only extraneous element found in appreciable quantity, this being due to the difficulty of obtaining metallic manganese sufficiently free from this element. Even, however, in the 39 per cent alloy, the silicon did not exceed 0.70 per cent, but reached 1.36 per cent in the 83 per cent alloy.

(a) *Cast Material*.—A total weight of between 50 and 60 lb. of each alloy was made, this being poured in the form of an ingot in a cast-iron mould. There were also cast a pair of bars 12 inches long by 1 inch square for transverse test, and strips 1 in. by $\frac{1}{4}$ in. by 7 in., these being cast in sand-moulds.

In all cases the steel poured in a fluid manner and settled very well in the chill and sand moulds.

(b) *Forged Material*.—For the purpose of carrying out tests on the alloys in their forged condition, a portion of each ingot was forged down under the steam-hammer to produce a sufficient quantity of bar of $1\frac{1}{8}$ inch diameter. From this bar were made the necessary tensile test-pieces, and from some of the alloys bar of smaller section, 11 mm. by 9 mm., was forged specially to provide shock test specimens.

In each case this was accomplished quite easily and successfully at a bright red heat (about $950^{\circ}\text{C}.$), though in some cases where an attempt was made to forge at a lower temperature (about $800^{\circ}\text{C}.$) the material was difficult to work and tended to crack.

(c) *Heat Treatment*.—In studying the mechanical and physical characteristics of these alloys it was thought well to examine each of them as far as possible, whether in the cast or forged state, in three different conditions, as regards heat treatment—namely, (a) as cast or forged; (b) as annealed, that is, by heating to a comparatively high temperature, 860° to $890^{\circ}\text{C}.$, and cooling very slowly; (c) as water-quenched from $1,000^{\circ}\text{C}.$ There were at the time no special grounds for assuming that either of the latter types of heat treatment would be more favourable than others for developing interesting or useful characteristics in these alloys; rough tests of a preliminary nature, in fact, indicated rather that heat treatment of any kind had nothing like such a pronounced influence on their qualities, as in the case of iron-manganese alloys containing a comparatively high percentage of carbon, including in these the material known as ‘manganese steel’.

Section 6.—Mechanical Qualities

Cast Material.—The mechanical tests on the cast material comprised, besides Brinell hardness tests, bending tests on the small cast strips and transverse tests on the 1 inch square bars resting on supports 12 inches apart. These bending and transverse tests are of a similar character to those employed by the author in his earlier published researches on alloy steels.

In addition, and in view of the remarkable characteristics displayed by manganese steel in this direction, a portion of each transverse bar was tested for its work-hardening qualities in the following way. Each specimen was hammered for a total period of fifteen minutes with a 3-lb. engineer's hammer, using the ball end of the head, the blow being concentrated inside a circle of 1 inch diameter. The Brinell hardness of the hammered surface was then measured and compared with its initial hardness. This method, while of a simple character and obviously dependent for its consistency upon the man employed for the purpose, has been found to give useful comparative results, developing in the case of manganese steel a hardness of over 600 Brinell. In the present case it was not desired to do more than obtain some approximate indication of the capacity of these alloys for work-hardening, it being intended to make more exact comparisons only if found desirable.

Forged Material.—In the case of the forged material tensile tests were taken, a complete record being obtained in each case of the yield point, maximum stress, elongation and reduction of area, and the type of fracture.

Shock tests were carried out in the Frémont test machine both with nicked and unnicked specimens. The test-pieces were of the usual Frémont pattern, namely, 10 millimetres broad by 8 millimetres deep and 30 millimetres in length, resting upon supports 22 millimetres apart. In the case of the nicked specimens the nick was 1 millimetre square, making the actual section of material at the nick 10 by 7 millimetres.

In the preparation of the tensile test-bars, although many of them proved difficult to machine—principally those from about 4 per cent manganese to about 14 per cent—in the original series of steels these were machined with screwed ends from the $1\frac{1}{8}$ -inch diameter bar, having been previously and where necessary brought by heat treatment into the physical condition required for the test. In the case of the later additional specimens, for the tensile test-piece the more expeditious method was adopted of forging nearly to size and shape before heat treatment, and subsequently grinding accurately to size on the middle test portion, the bars being pulled between serrated grips. The shock test-pieces were all prepared from the 11 millimetre by 9 millimetre bar.

Mechanical Qualities.—The mechanical qualities of the various alloys in their cast and forged forms in relation to their chemical analysis are shown in tables and diagrams as follows:

Table	VA	} Cast material, transverse and bending tests, with Brinell hardness and hammer-hardening qualities.
	VB	
	Vc	

Table	VIA	} Forged material, tensile and shock tests, and Brinell hardness.
	VIB	
	VIC	

Tables VIA, B, C see end of paper.)

Tables VII and VIII—The alloy with about 83 per cent manganese. Mechanical and physical qualities.

Figure 1.—Cast material, transverse strength.

Figure 2.—Cast material, Brinell hardness.

Figures 3, 4, and 5.—Forged material, tensile qualities.

Figure 6.—Forged material, shock qualities.

Figure 7.—Forged material, Brinell hardness.

(For Figures, see end of paper.)

An examination of their qualities in regard to these data shows that the alloys may be divided for convenience into ranges of composition expressed in the following Groups:

Group 1.—Manganese below about 4 per cent. In this range the alloys are comparatively soft and tough, but becoming harder and less tough with increasing manganese.

Group 2.—Manganese 4 to 10 per cent; characterised by a comparatively high Brinell hardness, in the region of 400, and brittleness.

Group 3.—Manganese 10 to 15 per cent; a transitional zone in which the ductility improves and the hardness decreases with increasing manganese.

Group 4.—Manganese 15 to 39 per cent; possessing to a limited extent the characteristics of manganese steel—that is, a comparatively low Brinell hardness, in the neighbourhood of 200, with considerable tenacity and ductility, and a capacity for workhardening to a considerable degree.

Group 5.—Manganese about 83 per cent; hard and brittle.

It is interesting to note that the alloy, 1379 I, containing 83.50 per cent manganese and only 0.29 per cent carbon, as shown by the data in Table VIII, has qualities not markedly different from those of ferro-manganese of the ordinary kind containing about 7 per cent of carbon, being of a glass-scratching hardness, quite brittle and not of a forgeable character, also non-magnetic. In this table are included also one or two types of low-carbon ferro-manganese as supplied and used industrially. These latter, while containing very much less carbon than the ordinary type of ferro-manganese—that is, under 1 per cent—are not quite so low in this element as the author's specially prepared alloy.

Table VII shows that the properties of the low-carbon alloys of this percentage may be modified to some extent by quenching in water from a temperature of 950° C. or over, this treatment resulting in a definite softening while not affecting their non-magnetic character. With slow cooling from similar temperatures the hardness as cast is retained, and very slight magnetic qualities appear. This increase in magnetism, although more apparent on the oxidised surface, is also definitely shown at the interior of the specimen.

Subsequently to the preparation of the main portion of this paper, the author made a further alloy, No. 1379 J, of the following composition:

C	Si	S	P	Mn	Fe
0.24	1.14	0.062	0.039	61.50	37.00 per cent

The object of this alloy was to give some indication of the characteristics to be found at an intermediate stage, in the rather wide gap between specimens H and I, with 38.90 and 83.50 per cent manganese. Owing to its late appearance the characteristics of this alloy do not appear in the various tables, and, in fact, no very thorough series of tests was attempted, such as was carried out in the case of the other alloys.

Table VII.—Iron-Manganese Alloy with about 83 per cent Manganese. Cast Material.
Various hardness and toughness tests, also magnetic quality with effect of heat treatment.

Analysis:

Specimen No. 1379 I		C	Si	S	P	Mn	Fe	14.75 (by diff.) per cent	
Specimen Mark	Treatment, Degrees Cent.	Hardness					Toughness	Specific magnetism (SCI=100 per cent)	Remarks
		Brinell	Scleroscope	Moh's scale	To file	Glass			
1379 I/1	As cast	693	102/105	7 (quartz) just scratches	Unfileable	Scratches glass easily	Utterly brittle	0.07	Small piece broke up with light blow of hand-hammer
1379 I/2	950 water	370	60 highest recorded	6 (feldspar) just scratches	Just fileable	Will not scratch. A very sharp corner with good pressure will occasionally just touch	Broke up Brinell testing	Nil	Small fragment about $\frac{1}{2}$ in. x $\frac{1}{2}$ in. x $\frac{3}{4}$ in. Treatment caused a network of cracks in these pieces
1379 I/3	" "	"	"	6 (feldspar) just scratches	" "	"	"	Nil	Large fragment roughly 1 in. x 1 in. x $\frac{5}{8}$ in. Appears to be entirely free from internal cracks after treatment
1379 I/4	950 furnace	670/705	98/102	7 (quartz) just scratches	Unfileable, crumbles; takes teeth off file	Scratches easily	"	0.15 (Rather more magnetic in places than specimens 5 and 6.)	
1379 I/5	1150 water	545/600	83/89	7 (quartz) just scratches	" "	"	"	0.15	Small fragment about $\frac{1}{2}$ in. x $\frac{1}{2}$ in. x $\frac{3}{4}$ in. Both pieces badly cracked after treatment
1379 I/6	" "	340	56	6 (feldspar) just scratches	Fileable, but very stiff	Will not scratch. A very sharp corner with good pressure will occasionally just touch.	"	0.15	Large fragment roughly 1 in. x 1 in. x $\frac{5}{8}$ in.
1379 I/7	1150 furnace	670/705	98/102	7 (quartz) just scratches	Unfileable, crumbles; takes teeth off file	Scratches easily	"	0.35	Appears to be entirely free from internal cracks after treatment. On removing the specimen from its envelope two or three days after treatment, flakes suddenly splashed off its surface.

Table VIII.—Physical Properties of Iron-Manganese Alloys containing about 83 per cent Manganese with Varying Carbon.

Specimen No.	Description	Analysis			Fracture	Specific gravity	Hardness					Toughness
		C %	Si %	Mn %			Brinell	Scleroscope	Moh's scale	To file	Glass	
1379 I	Specially prepared	0.29	1.36	83.50	Dull silvery	7.26	693	102/105	7 (quartz) just scratches	Unfileable	Scratches glass easily	Utterly brittle
5426	Low-carbon ferro-manganese	0.58	5.22	79.10	Bright silvery	7.07	670	98	7 (quartz) just scratches	"	"	"
5419	Low-carbon ferro-manganese	0.94	0.66	79.34	Glistening silvery	7.43	610/640	90/94	7 (quartz) just scratches	"	"	"
5517	Ordinary ferro-manganese	7.07	0.76	79.10	Dull silvery	7.31	Too brittle to obtain test	97	9 (corundum) scratches	"	"	"

All the above materials are quite non-magnetic to a hand-magnet.

Briefly, it may be said that the material did not forge successfully at any temperature from 800°C. to 1,100°C. A transverse bar in the condition as cast broke under a load of 3,810 lb., with a bending angle of 2°; its Brinell hardness was 159. For a similar bar in the water-quenched condition the breaking load was 5,500 lb., with a bending angle of 31° and a Brinell hardness of 185.

Generally, the mechanical qualities of such an alloy seem to be much of the kind to be expected from an alloy intermediate between specimens H and I. As regards forgeability, H, with 38.90 per cent manganese, is readily forgeable; I, on the other hand, with 83.50 per cent manganese, is quite intractable. It is not altogether surprising, therefore, to find that the 60 per cent alloy could not be forged. Although it is hardly probable, nevertheless in similar material containing only minute traces of carbon this remark might require some modification.

The transverse bars too, which with 38.90 per cent manganese show greatly increased toughness as compared with the alloys of lower percentage, show with 60 per cent manganese a marked falling off again in toughness, as might be expected, in view of the complete brittleness of the 83 per cent alloy. The 60 per cent alloy, however, retains to some degree the characteristic of toughening by water-quenching.

The other physical qualities of the alloy J are referred to later in Section 9.

*Section 7.—Comparison of the Mechanical Qualities
obtained by the Author with those of other Investigators*

In several of the tables and figures mentioned in detail below, comparisons have been made, where possible, between the mechanical qualities shown by the alloys in this research and those determined for the similar alloys examined in the researches of other investigators mentioned in Section 3. In making these comparisons, it should, however, be borne in mind that the heat treatments are usually not precisely similar, and in the case of forged material the size of the ingot from

which the forging was prepared, also the amount of the reduction in forging, and the temperature, were not necessarily the same. Any comparison on the basis of material in its condition just as forged without any further heat treatment is specially subject to qualification, this being a somewhat undefined physical condition dependent on the factors mentioned.

From these comparisons it will be seen that while there is a broad and general agreement as to the character of the alloys at the different manganese percentages, there are disparities in individual cases, specially as regards the degree of toughness or brittleness displayed by an alloy with certain percentages and with particular types of treatment. These differences are not always readily explainable, though the author has where possible, by tests on alloys of similar percentages, endeavoured to test the accuracy of his own observations. In addition, tests have been made by the author on specimens kindly supplied to him by Professor Arnold of the materials prepared for his (Arnold's) research, already mentioned, and these tests give results on the whole agreeing with those obtained with the author's series of alloys. The author, therefore, believes the results obtained will be found to be in concordance.

In the paper by Arnold and Knowles in 1906 referred to, the properties reported for the alloy containing about 4 per cent manganese (Table X), essentially different from those obtained by Guillet, were mentioned, and some discussion took place on this point. Guillet's alloy No. 5 in question (Table IX) containing 4.2 per cent manganese shows a very marked minimum of hardness and a maximum of toughness, dividing the series at this point into groups on either side possessing distinctly higher hardness and less toughness than itself. A reference to Figures 8 to 11 indicates that these same comparative features exist also in the tensile test as well as in the Frémont shock test, whether these be carried out on the material representing the water-quenching condition or the condition as forged.

	Quenched (900° C. water)										
	0.034	1.328	0.005	0.011	6.139	53.53	75.12	0.2	0	3	444
7	0.034	1.328	0.005	0.011	6.139	53.53	75.12	0.2	0	3	444
8	0.172	1.362	trace	0.010	10.512	31.05	61.41	4.0	0	4	293
9	0.156	0.292	0.010	0.016	12.920	19.05	41.59	3.5	6.0	12	248
10	0.224	0.911	trace	0.024	14.400	14.80	50.23	10.0	14.7	27	212
11	0.114	0.421	0.004	0.010	20.880	22.48	58.36	20.5	17.5	25	192
12	0.396	0.505	0.005	0.018	33.480	21.72	38.99	45.0	74.6	28	134
	Quenched (900° C. water)										
	0.082	0.163	0.012	0.015	0.432	16.70	28.19	17.0	74.2	39	105
1	0.082	0.163	0.012	0.015	0.432	16.70	28.19	17.0	74.2	39	105
2	0.073	0.320	0.009	0.011	1.296	37.34	40.64	9.0	62.1	22	196
3	0.104	0.457	0.008	0.032	1.728	28.19	41.44	3.5	39.6	16	234
4	0.237	0.781	0.010	0.032	2.150	67.88	67.88	1.0	5.0	13	248
5	0.058	0.304	0.025	0.020	4.200	21.02	34.48	10.0	73.4	26	126
6	0.276	1.100	trace	0.015	5.6	42.86	42.86	1.0	0	2	418
7	0.034	1.328	0.005	0.011	6.139	50.16	50.16	0.5	0	0	444
8	0.172	1.362	trace	0.010	10.512	21.53	50.23	2.5	8.2	3	300
9	0.156	0.292	0.010	0.016	12.920	19.05	49.37	6.0	5.8	8	269
10	0.224	0.911	trace	0.024	14.400	31.05	42.98	5.25	12.5	18	235
11	0.114	0.421	0.004	0.010	20.880	25.08	56.45	15.0	14.7	25	179
12	0.396	0.505	0.005	0.018	33.480	21.53	40.20	47.0	73.5	33	114

Table X.—Forged Material

(Analyses and mechanical tests on iron-manganese alloys from papers by Arnold and Knowles, Journal of the Iron and Steel Institute, 1911, and J. O. Arnold, *ibid.*, 1910)

Specimen mark	Analysis, Per cent					Treatment	Tensile test			
	Carbon	Silicon	Sulphur	Phosphorus	Manganese		Yield point. Tons per sq. in.	Maximum stress. Tons per sq. in.	Elongation per cent on 2 in.	Reduction of area. Per cent
952 A	Under 0.1	.....	.....	.....	1.10	Annealed	19.04	24.48	43.5	79.7
B	0.06	0.08	0.030	0.020	1.04					
977 A	Under 0.1	.....	.....	.....	3.10	"	34.56	41.42	25.0	63.2
961 A	" 0.1	.....	.....	.....	4.10	"	20.56	53.48	25.5	42.4
B	0.08	0.05	0.034	0.020	4.86					
957 A	Under 0.1	.....	.....	.....	5.50	"	38.68	65.96	28.5 (on 0.9")	38.1
B	0.06	0.08	0.036	0.019	5.96	"	45.0	72.50	4.4	2.04
951 A	Under 0.1	.....	.....	.....	10.50	"	30.80	57.88	1.0	0
956 A	" 0.1	.....	.....	.....	12.90					
B	0.08	0.15	0.055	0.020	12.84	"	19.80	56.12	6.5	4.6
967 A	Under 0.1	.....	.....	.....	15.70	"	37.80	63.72	17.5	20.6
955 A	" 0.1	.....	.....	.....	19.85	"	22.32	55.04	30.0	22.5
B	0.07	0.20	0.067	0.019	22.93					
966 A	0.14	.....	.....	.....	30.60	Normalized	19.7	41.6	58.0	65.1

Note.—A = Approximate analysis figures given in Arnold and Knowles' paper.

B = Analyses and mechanical test carried out by the author on bars received from Professor Arnold.

Such results would indicate that about 4 per cent manganese in the alloys is to be in the nature of a critical percentage, and therefore of some importance in discussing the relations between iron and manganese. The author's results obtained from alloy B, however, do not show such critical character, but properties intermediate between those of the two adjoining alloys A and C1, and form a link between Group 1, the comparatively soft and tough alloys, and Group 2, the hard and brittle alloys. To confirm this the author thought it necessary to make a further alloy, B4, with an even closer similarity in manganese percentage to Dr. Guillet's alloy. As will be seen from the figures in Tables VA, B, and C, and Figures 3 to 7, this gave results fully bearing out the brittle and comparatively hard nature of the alloy of this percentage, as shown by the author's original series.

The additional alloy, B3, with 4.8 per cent manganese, also goes to confirm the sequence of mechanical qualities indicated by the original series.

With regard to the variation in Brinell hardness with manganese percentage, where this can be compared, that is, for the forged material in its untreated and water-quenched conditions, although in a general way both Guillet and the author indicate a similar progression with increase in manganese, there are certain essential points of difference. In each case the hardness rises to a maximum of about 450 as the manganese is increased, but with higher percentages falls away again. This maximum in the Guillet series is reached at a manganese percentage of 6.14, while in the author's it is at 9.45 per cent manganese. An interesting feature of the results obtained with the author's specimens is the indication in the curves of a secondary maximum in hardness at 4.82 per cent manganese above which the hardness shows a tendency to remain stationary, or even to fall slightly up to 6.68 per cent manganese, then rising again to the maximum of 460 in the 'as forged' condition referred to at 9.45 per cent manganese. In the specimens containing the higher percentages of manganese, from 15 to 39 per cent,—that is, in the materials coming into Group 4—the hardness of the author's alloy is rather higher than that obtained by Guillet.

Table XII and Figure 14 show that, so far as comparison can be made between Brinell and scleroscope hardnesses, the results of Kasé and the author, obtained on cast material, are in satisfactory agreement, the general features above referred to and displayed by the forged material being noticeable. Both series also indicate a general reduction in hardness for the whole series of alloys by annealing, although in respect of both the untreated and the annealed material the physical conditions are not strictly comparable.

It will be observed that the scleroscope hardness figures obtained by Kasé when translated into approximate Brinell hardness figures for comparison with the author's do not in any case indicate so high a hardness as the author's figures. While the comparison of scleroscope and Brinell hardnesses must always necessarily be approximate, there is no doubt that the scleroscope figures obtained by Kasé are generally too low, probably due to the very small size of the specimen preventing a true rebound—a fact well known to users of the scleroscope. As a check the author made scleroscope determinations on specimen D with 9.45 per cent manganese at the end of 1 inch square cast bars and obtained figures of 63 for the material as cast and 60 for the annealed material, compared with figures of 43.1 and 34.5 for the 10 per cent alloy obtained by Kasé.

A similar slight but distinct softening by annealing is also shown in Figure 7 for the forged material. Water-quenching, on the other hand, increases slightly the hardness of the forged material up to about 7 per cent manganese. Above 14 per cent manganese water-quenching treatment results in a slight softening. At the intermediate percentages, namely, from 7 to 14 per cent, such treatment appears to have very little effect on the hardness.

The series of shock tests (Table XI and Figure 13) carried out by the author on material received from Professor Arnold, with subsequent water-quenching in a similar manner to the author's own specimens, gives results in excellent accord with those of the author's series, and clearly establishes

the brittle character of the range of alloys in Group 2 from about 4 to about 10 per cent of manganese—that is, so far as the water-quenched condition is concerned. The rather rapid loss of toughness due to the first addition of manganese up to 4 per cent is also clearly seen, toughness being gradually restored to the material by additions of manganese above about 10 per cent. While the results obtained by Guillet (Figures 10 and 11), when the 4 per cent alloy previously discussed is left out of account, show the same general characteristics, he indicates a much greater toughness both in the 'as forged' and the water-quenched material for the alloys of high percentage, that is, above the brittle range.

Turning to the tensile qualities, it will be noticed that while the toughness, as determined both by shock tests and by the Brinell hardness, indicates a systematic and fairly progressive relationship to the manganese percentage, the tensile qualities, particularly in regard to the maximum stress developed, display a somewhat erratic relationship in the first two or three groups, and particularly in the brittle range, Group 2. This erratic character is a feature not only of the author's results, but also of those of Arnold and Guillet. The author is inclined to believe that the essentially brittle character of the alloys of this Group makes their tenacities liable to abnormal variations. With brittle materials it is well known that the maximum stress developed in the tensile test is very much affected by slight differences in the degree of finish of the specimen and in the method of applying the load; with such materials it is consequently very difficult to arrive at a very exact tenacity without taking the most elaborate precautions. Comparison of the results of the various researches is therefore rendered rather difficult. The author's results show, however, that generally the characteristics seen in the shock and hardness tests are also displayed in the tensile tests. The untreated and the water-quenched materials show in the brittle zone, Group 2, a low elongation and reduction of area, though the tenacity is not commensurate with the Brinell hardness, possibly for the reasons above mentioned.

Table XI.—Shock and Brinell Hardness Tests carried out by the Author on Iron-Manganese Alloys supplied by Professor J. O. Arnold. Shock Test-Pieces forged from Bars 1 inch in diameter and quenched in Water from 1,000° C. Forged Material.

Specimen No.	Analysis. Per cent					Frémont Shock test (nicked)			Brinell hardness
	Carbon	Silicon	Sulphur	Phosphorus	Manganese	Kg.-m.	Ft.-lb.	Angle. Degrees	
952	Under 0.1	.....	.....	.....	1.10	22.0	159	Double unbr.	136
	0.06	0.08	0.030	0.020	1.04				
977	Under 0.1	.....	.....	.....	3.10	4.0	29	4	410
	" 0.1	.....	.....	.....	4.10	2.0	14	3	398
961	0.08	0.05	0.034	0.020	4.86				
	Under 0.1	.....	.....	.....	5.50	0.5	4	1	398
957	0.06	0.08	0.036	0.019	5.96				
	Under 0.1	.....	.....	.....	10.50	Nil	Nil	Nil	423
951	" 0.1	.....	.....	.....	12.90	3.5	25	11	286
	0.08	0.15	0.055	0.020	12.84				
967	Under 0.1	.....	.....	.....	15.70	12.0	87	55	183
	" 0.1	.....	.....	.....	19.85	5.5	40	37	224
955	0.07	0.20	0.067	0.019	22.93				

Note.—A = Approximate analysis figures given in Arnold and Knowles' paper.

B = Analyses carried out by the author on bars received from Professor Arnold.

Table XII.—Analyses and Scleroscope Hardness of Iron-Manganese Alloys from paper "On the Structural Diagrams of Some Special Steels," by T. Kasé, Science Reports to the Tôhoku Imperial University, 1925. Cast Material

Analysis		Scleroscope Hardness	
Carbon Per cent	Manganese Per cent	Cooled from melt in furnace	Annealed at 800° to 900° C. for about 5 hours in vacuum and cooled in furnace
trace	2	16.5	12.5
"	4	22.8	22.7
"	6	42.0	32.5
"	8	42.2	33.3
"	10	43.1	34.5
"	12	36.9	26.2
"	15	34.1	27.5
"	20	20.8	20.4
"	30	16.7	15.3
"	40	13.8	12.4

Burgess and Aston, with their alloy containing 4.51 per cent manganese, of which, however, the full composition is not known, obtained a tenacity of 87.50 tons per square inch, with entire absence of elongation or reduction of area, the yield point being coincident with the maximum stress, and the material totally brittle under the tensile test. The physical condition of the material is not stated. If annealed, their result indicates a more brittle character for the alloy of this percentage than the author's, whose two nearest alloys, Nos. B/4 and B/3, gave elongations of 4.5 and 15 per cent respectively in the annealed condition. In their unannealed and water-quenched conditions, however, these two alloys were, like that of Burgess and Aston, practically devoid of ductility. These investigators apparently carried out tensile tests on other members of the series than the three for which the results were recorded, since they

state that 4.51 per cent manganese is in the region of great strength and brittleness—a remark more generally confirming the author's description of the range of alloys comprising what has been described as Group 2.

For their alloys containing 0.505 and 10.419 per cent manganese, also in an undescribed physical condition, Burgess and Aston obtained tensile figures in general accord with Guillet, Arnold, and the author, their figures being: for the 0.506 per cent alloy, yield point 20.2 tons per square inch, maximum stress 25.5 tons per square inch, elongation 31 per cent, reduction of area 76 per cent; and for the 10.419 per cent alloy, yield point 28.8 tons per square inch, maximum stress 39.7 tons per square inch, elongation 6 per cent, reduction of area 4.1 per cent.

Burgess and Aston also referred to the necessity for grinding in the preparation of test specimens in the case of the alloys containing more than 3 per cent manganese, thus confirming the author's experience, with regard to the extreme hardness of this type of material.

Annealing, which may be described as heating to about 870°C. and cooling very slowly, appears to effect a definite improvement in the ductility of the alloys up to 17 per cent manganese, though in some cases this improvement is only slight. From the annealed material, however, the author has not obtained generally such high figures for the elongation as those shown by Arnold (Figure 12). In view of this difference the author prepared and tested a tensile bar from Professor Arnold's alloy No. 957A containing 5.5 per cent manganese, after submitting it to an annealing treatment similar to that described by him, with the result which is included in Table X, an elongation of only 4.4 per cent being obtained as compared with 28.5 obtained by Arnold. The analysis of the bar tested by the author shows that this contained rather more than 5.5 per cent manganese, namely, 5.96, but this difference is insufficient to account for the marked difference in elongation. Frémont shock tests also taken on the specimens treated by the author gave figures of 0.6 kilogramme-metre for the nicked specimen with angle of bend nil, and for an unnicked specimen 6.2 kilogramme-

metres with an angle of $4\frac{1}{2}$ degrees, thus showing that the brittleness under shock of the alloys in Group 2 is not materially affected by annealing.

For his alloy containing 5.88 per cent manganese Strauss obtained an elongation figure of 1.3 per cent in the annealed condition. His specimen, however, was roaked and broke prematurely, and so, unfortunately, does not provide the information as regards the effect of annealing on this particular percentage which it might otherwise have done. In the water-quenched condition in which both Guillet and the author obtained for this percentage a quite low elongation of not more than about 1 per cent, Strauss on the other hand obtained an elongation of 12 per cent on a bar which also broke prematurely—indicating, therefore, a still higher ductility for a truly representative specimen. As regards the effect of annealing on alloys containing more than 17 per cent of manganese, this seems from the author's results to point slightly but definitely in the direction of reducing the ductility.

Section 8.—Magnetic and Electrical Qualities

From the results of this research it will be seen that, in the types of low-carbon steel obtained, the metal manganese has not produced material of any particular value for electrical purposes. In view of the fact that manganese steel, containing about 13 per cent manganese and 1.25 per cent carbon, is practically non-magnetic, it was hardly to be expected that in the absence of carbon, as in the alloys dealt with in this paper, this characteristic of non-magnetic susceptibility would be strongly modified in the way now shown to be the case. Similar absence of magnetic susceptibility to that just mentioned is shown by specimen 'G' in the present research, the steel containing 0.15 per cent carbon and 17.00 per cent manganese, this being 4 per cent higher in manganese than the non-magnetic manganese steel containing 13 per cent manganese with 1.25 per cent carbon.

Table XIII has been prepared to show the specific magnetism of these two classes of alloys of iron and manganese in their water-quenched condition.

Table XIII.--Comparison of the Specific Magnetism of Iron-Manganese Alloys containing (a) Low-Carbon and (b) Carbon about 1 per cent in their Condition as Water-Quenched from 1,000°C.

The materials are arranged in order of increasing manganese.

Carbon Per cent	Manganese Per cent	Specific magnetism	
		(a) Low-carbon	(b) Carbon about 1 per cent
0.11	0.06	90	..
1.05	0.09	..	76
0.07	1.68	92	..
1.00	1.94	..	16
1.10	3.89	..	2.10
0.06	3.95	89	..
0.10	4.10	75	..
0.11	4.82	75	..
0.06	6.68	87	..
0.08	6.75	90	..
1.00	6.87	..	0.16
0.07	9.45	55	..
0.98	10.33	..	0.07
1.11	11.93	..	0.06
0.09	12.95	12	..
0.14	14.30	1.50	..
1.16	15.60	..	0.06
0.15	17.10	0.04	..
1.04	18.90	..	0.10
0.08	22.70	0.02	..

The data for the alloys containing about 1 per cent carbon are also shown in Figure 15, where they may be similarly compared with those for the alloys containing low carbon. These data show that while, as mentioned, non-magnetic qualities are obtained even in the practical absence of carbon, the presence of carbon results in non-magnetic qualities appearing at a much lower manganese percentage

than in its absence. With about 1 per cent of carbon present not more than 7 per cent of manganese is necessary, while with low carbon 16 per cent or more of manganese is required, that is, to take away or suppress the magnetic qualities of the iron. It will be thus seen that the non-magnetic qualities and want of susceptibility of these iron manganese alloys are largely influenced by the proportion of the element carbon present in the steel.

In the series of joint papers regarding the magnetic qualities of various steels, read by Barrett, Brown, and Hadfield, before the Royal Dublin Society, 1898–1903, were included investigations relating to a series of alloys containing varying amounts of manganese with comparatively low carbon content. For each of these steels full magnetisation curves were obtained in the form of ‘hysteresis loops’, and for a magnetic force of 45 c.g.s. units. The complete results are given in Table XIV of the original paper, including the chief magnetic characteristics as regards magnetic induction, retentivity, and coercive force, and are reproduced here in Table XIV.

Table XIV.—Magnetic Qualities of a Series of Iron-Manganese Alloys with Low Carbon, Forged and Annealed Material.

Mark	Analysis		Maximum induction, H=45	Re-tentivity	Coercive force	Per-meability for H=8	Hysteresis Ergs per cycle
	Carbon Per cent	Manganese Per cent					
Iron	0.03	0.03	17480	7120	1.66	1560	11090
48	0.20	0.50	16700	8730	3.20	1020	20460
4147	0.24	1.00	16200	9990	3.40	1000	23090
53	0.41	2.25	15400	9990	6.00	990	31860
1379 B	0.08	3.50	12530	8950	17.80	....	.....
39	0.36	4.00	9800	6080	16.20	130	41070
34	0.36	4.75	8730	5590	19.60	75	41000
1379 D	0.16	10.10	670	250	15.00	....	.....
1338	0.26	13.00	280	Too small to measure accurately		0	980
1379 D/2	0.15	15.20	0			....	.....

It is pointed out in the paper that when the manganese percentage reaches a figure of between 3 and 4 per cent a great drop takes place in the maximum induction with a corresponding rise in the coercive force. A further increase in the manganese content to between 7 and 10 per cent seems to have much less effect upon the magnetic properties. With 13 per cent manganese non-magnetic qualities are practically reached, but it is not until 15.20 per cent that there is a complete absence of measurable magnetism.

A further and similar series of steels, containing a comparatively high percentage of carbon, namely, up to about 1 per cent, was also examined, bringing out in a striking manner the influence, already referred to, of carbon on such alloys. Its actual effect in respect of magnetic qualities was clearly to reduce the magnetisability, resulting in a considerable reduction of the maximum induction attained, and in the case of those alloys containing the higher percentages of manganese, although still less than 13 per cent, in their becoming completely non-magnetic, whereas with sufficiently low carbon they show appreciable magnetic properties.

Burgess and Aston, in their research already referred to, carried out tests of a similar character, determining the maximum induction, retentivity, and coercive force for several different values of the magnetising force. In general, their results confirm those of the Royal Dublin Society research previously referred to—that is, in indicating a reduction in the magnetic quality with increase of manganese percentage. In their case, however, the decrease is not quite so regularly progressive.

The chief point of difference between the two researches is shown in the case of the alloy containing about 10 per cent manganese. Burgess and Aston find that their alloy containing 10.42 per cent manganese (by analysis), under each condition of heat treatment tested gives figures for its magnetisation value so low that it may be regarded as a non-magnetic alloy. In the research above mentioned, and in all other tests for saturation magnetism, quite appreciable magnetic qualities have been found for an alloy of about this composition and, as previously mentioned, complete

non-magnetism is not arrived at before a percentage of 15 or 16 per cent manganese is reached. It would seem that the probable explanation may lie in the unsuspected presence of carbon in Burgess and Aston's alloy—carbon, as has been shown, having a marked effect in this respect. Such an explanation may also account for the lack of regularity in magnetic qualities shown in Burgess and Aston's results in relation to manganese percentage, coupled with the fact that the alloys have not in every case been analysed, and the compositions given are therefore only approximate.

Specific magnetism.—The joint research carried out by the author and the late Professor B. Hopkinson, on "The Magnetic Properties of Iron and its Alloys in Intense Fields" ⁽¹⁾, comprised a wide range of steels of various types, and included certain alloys of iron and manganese with comparatively low carbon, although not so low as in the series described in the present paper. The degree of magnetisation acquired by those alloys in an intense magnetic field was determined and compared with that for a specimen of pure iron, the figure obtained in that way being described as the 'specific magnetism' of the particular specimen.

The general result of that research was to show that manganese has a similar effect in progressively reducing the magnetisability of iron in intense fields to that observed in the research above referred to for weaker fields up to 45 c.g.s. units.

In a further research carried out by the author in collaboration with the late Professor Kamerlingh Onnes and Dr. H. R. Woltjer ⁽²⁾, the specific magnetism of a further series of iron-manganese alloys of low carbon content was also determined. It was thought desirable, however, to obtain similar information from the more complete series of the present research. For this purpose specimens $\frac{1}{4}$ inch square by $1\frac{1}{4}$ inch long were machined from forged bars in three different conditions, namely, 'as forged', annealed, and water-quenched, in a similar way to those for the mechanical

⁽¹⁾ *Journal of the Institution of Electrical Engineers*, 1911, Part 206, vol. xlv

⁽²⁾ "On the Influence of Low Temperatures on the Magnetic Properties of Alloys of Iron with Nickel and Manganese," *Proceedings of the Royal Society*, 1921, (A), vol. xcix.

tests; a bar was also in each case quenched in water from 1,000° C. and afterwards reheated to 500°C. for sixty hours, a treatment which in the case of manganese steel confers upon it strongly magnetic properties. The full reasons for applying such treatment to a series of iron-manganese alloys are mentioned in the paper cited. The specimens were tested by the apparatus described in the paper above mentioned, by which the force of their attraction by a permanent magnet was measured. This method, although of a simple character and giving results necessarily approximate, has been found to agree in its indications with those obtained from more elaborate apparatus.

The results of the tests are shown in Table XVI and in Figure 15. The features indicated in the Hadfield-Onnes research are confirmed, that is, notwithstanding the very low carbon percentage of the alloys it was found that at about 16 per cent of manganese the alloys become almost completely non-magnetic, the falling off in magnetism occurring in two stages, namely, a fairly slow drop from 0 to 7 per cent manganese and a more rapid one from 7 per cent to about 16 per cent. It is further shown in the present research that the non-magnetic qualities remain up to a manganese content of 39 per cent, the 60 and 80 per cent alloys also having this characteristic, which, of course, is the case with manganese metal unalloyed with iron.

The author's results in respect of the percentage of manganese necessary to confer non-magnetic qualities upon iron in the absence of carbon are thus in full agreement with those obtained in the previous researches mentioned, and also by T. Kasé, who found that magnetic qualities disappeared between 15 and 20 per cent manganese.

As regards the specimens reheated to 500°C. for sixty hours, it will be seen that their specific magnetism remains, in all cases, practically the same as in the original water-quenched condition; such differences as appear are probably within the limit of experimental error. The fact previously noted in the joint paper referred to, that iron-manganese alloys, in contradistinction to manganese steel, are not affected in their specific magnetism by such heat treatment,

is fully confirmed. The behaviour of manganese steel in this connection seems, therefore, to be due to its carbon content, and the author explains its action in the following way.

The carbide, which is deposited by annealing from alloys containing about 12 per cent manganese, has been shown by Arnold to be a double carbide having the formula $3\text{Fe}_3\text{C}.\text{Mn}_3\text{C}$, and, with 15 per cent manganese, $2\text{Fe}_3\text{C}.\text{Mn}_3\text{C}$; with alloys below about 13 per cent manganese the former carbide is deposited, while if the manganese percentage exceeds this the carbide is of the latter form.

In either case, therefore, appreciable quantities of iron and manganese are deposited with the carbon. In the former case for every 0.1 per cent carbon, 1.05 per cent iron and 0.34 per cent manganese are deposited from the steel, the manganese being about one-third of the amount of iron. The latter case corresponds to 0.93 per cent iron and 0.46 per cent manganese for each 0.1 per cent carbon—that is, the amount of manganese is about half that of the iron.

In any alloy containing manganese to the amount of less than 33 per cent of the iron present, such deposition of carbide by heat treatment must therefore result in a reduction of the manganese percentage in the remaining material, *i.e.*, in what may be called the matrix. In the case, therefore, of manganese steel containing, say, 12 per cent manganese and 1.25 per cent carbon, and supposing all the carbon to be deposited by heat treatment, in this case as $3\text{Fe}_3\text{C}.\text{Mn}_3\text{C}$, it can be simply calculated that the steel now consists of a carbon-free matrix having the percentage composition 9.5 per cent manganese, in which the precipitated carbide is distributed. The indications from the present research show that an alloy of iron and manganese of this percentage has a specific magnetism of about 45 per cent. Since the carbide when isolated and examined by the author has proved to be non-magnetic, the steel as a whole will therefore be expected to display a specific magnetism of about 45 per cent, somewhat 'diluted' however by the presence of about 18 per cent, by weight, of non-magnetic double carbide. This deduction is in quite reasonably close agreement with the actual figure

obtained by heat treatment of manganese steel. The same explanation would naturally account for the practical absence of such a magnetic change in iron-manganese alloys low in carbon.

This question of the magnetic or non-magnetic properties of iron and its alloys with manganese is most important, because certain theories maintain that some of these, if cooled down to a sufficiently low temperature, would become magnetic. The results of a considerable number of experiments at temperatures of $-252^{\circ}\text{C}.$, and even $-269^{\circ}\text{C}.$, referred to in the joint paper by Onnes, Woltjer, and the author, read before the Royal Society in 1921, show such theories to be incorrect.

Electrical resistance.—In the Royal Dublin Society research previously referred to, in addition to the magnetic qualities of the specimens of the iron-manganese alloys with comparatively low carbon content, their specific electric resistance was also determined in both the condition as rolled and after annealing, the latter being the identical condition in which the magnetic tests were carried out. The results are reproduced in Table XV.

Table XV.—Electrical Resistance of a Series of Iron-Manganese Alloys with Low Carbon

Mark	Analysis		Specific Resistance, microhms per c.c.	
	Carbon Per cent	Manganese Per cent	As rolled	Annealed
48	0.20	0.50	14.96	14.46
4147	0.24	1.00	24.94	23.57
53	0.41	2.25	31.86	29.18
1379 B	0.08	3.50	31.29	29.67
39	0.36	4.00	33.74	28.69
34	0.36	4.75	38.23	29.38
32	0.32	5.15	46.50	37.41
1323 C	0.15	5.40	46.51	33.74
1338 B/2	0.26	13.00	63.70	61.50
1379 D/2	0.15	15.20	67.00	64.94

As in the case of the magnetic tests given above, and in view of the greater completeness of the present series, also its more satisfactory nature as regards freedom from carbon, it was thought advisable to submit them to a similar test for resistance. The test-pieces quenched in water from $1,000^{\circ}\text{C.}$, which served for the test of specific magnetism, were employed for the purpose. The electrical resistance was determined by the fall of potential method on bars $\frac{1}{4}$ inch in diameter by 12 inches long, and gave the results indicated in Table XVI and Figure 15. The figures obtained for the electrical resistance at various percentages are in reasonable agreement with those in Table XIII, and also the results obtained by Burgess and Aston. Exact agreement is not altogether to be expected, considering on the one hand the rather high carbon percentages in the alloys in Table XV, and the fact that the actual compositions of Burgess and Aston's alloys were not determined, the manganese percentages being those calculated from the mixtures used—not always a reliable procedure with alloys—and nothing being known as to the amounts of other elements possibly present. It will be seen from the author's data that the electrical resistance increases much more rapidly with the first additions of manganese to iron than with the higher percentages, but in a fairly progressive way. Beyond this the results do not call for special comment, except to remark that it is curious to find that in respect of their electrical conductivity, iron-manganese alloys show nothing of the critical behaviour seen in respect both of their magnetic and mechanical qualities in relation to manganese percentage. The essential differences in the underlying atomic or molecular features influencing electrical conductivity and magnetic properties respectively—a fact well known to physicists—are therefore clearly apparent from the examination of these alloys.

Section 9.—Critical Ranges on Heating and Cooling

SOME discussion regarding the critical ranges of iron-manganese alloys was presented in the joint paper before referred to by Onnes, Woltjer, and the author. This, however,

Table XVI.—Electrical Resistance and Specific Magnetism of Forged Material.

Group No.	Specimen mark	Analysis, Per cent					Electrical resistance (water-quenched from 1,000° C.) Microhms per c.c	Specific magnetism			
		Carbon	Silicon	Sulphur	Phosphorus	Manganese	Iron (by diff.)	As forged	Annealed	Water-quenched from 1,000° C.	Water-quenched from 1,000° reheated at 500° C. for 60 hours
1	1727 D	0.11	0.20	0.049	0.059	0.06	99.52	90	90	90	90
1	1379 A	0.07	0.03	0.120	0.070	1.68	98.03	96	90	92	90
2	1379 B	0.06	0.09	0.098	0.068	3.95	95.73	87	80	89	93
2	1379 B/4	0.10	0.16	0.053	0.056	4.10	95.53	75	75	75	92
2	1379 B/3	0.11	0.19	0.047	0.049	4.82	94.78	75	75	75	92
2	1379 C/1	0.06	0.12	0.081	0.064	6.68	92.99	77	77	87	87
2	1379 C/2	0.08	0.08	0.076	0.064	6.75	92.95	79	75	90	87
2	1379 D	0.07	0.10	0.084	0.059	9.45	90.24	48	45	55	45
3	1379 E	0.09	0.12	0.103	0.050	12.95	86.69	9	7	12	7
3	1379 E/3	0.14	0.26	0.051	0.044	14.30	85.21	4.0	1.0	1.5	1.0
4	1379 G	0.15	0.35	0.060	0.051	17.10	82.29	0.02+	0.04	0.04	0.20
4	1379 F	0.08	0.13	0.054	0.046	22.70	76.99	0.02—	0.01	0.02—	0.01
4	1379 H	0.20	0.70	0.055	0.036	38.90	60.11	0.01+	0.01—	0.01	0.01—

had more specific reference to the magnetic transformations, and was directly concerned with the explanation as to why the alloys containing about 16 per cent manganese and above are non-magnetic. Dr. Gumlich had determined the temperatures at which the magnetic transformations take place in such alloys containing up to about 13 per cent manganese, but so far as the author is aware their critical temperatures in respect of other properties had not been determined.

The author has therefore prepared the heating and cooling curves, shown in Figures 16 and 17, of the inverse rate type instituted by Professor Osmond. These were made on selected specimens representing stages in manganese percentage up to 17.10 per cent manganese and in their forged condition; a similar determination was also made on 1379I containing 83.50 per cent manganese, the series being eventually completed by the addition of material J with 61.50 per cent manganese. Both these high-percentage alloys were necessarily examined in their cast condition. In addition to these heating and cooling curves showing thermal changes, observations, shown on the same diagrams, have been taken of the temperatures at which loss and regain of magnetism occur—that is, for those specimens which are magnetic at ordinary temperatures.

To obtain the inverse rate curves described in this paper the author employed the usual methods, that is similar to those described in his paper on "Heating and Cooling Curves of Manganese Steel," read before this Institute in 1913, with the exception that an electric furnace was used instead of a gas furnace. A uniform maximum temperature of $1,100^{\circ}\text{C}$. (actually, $1,098^{\circ}$ to $1,107^{\circ}$) was adopted, and the specimens were each heated under the same conditions so as to be comparative. In cooling, the presence of critical points at comparatively low temperatures in the alloys with the higher percentages of manganese rendered it necessary to take a second cooling curve at a more rapid rate, so that the cooling was not unduly slow at the lower temperatures, with risk of masking to some extent the critical points.

For the purpose of determining the magnetic transformations, a separate heating of the specimens was made inside a refractory tube wound with a magnetising coil of non-

magnetic nickel-chromium alloy wire, the whole being placed in an electric furnace. A magnetising field of 15 c.g.s. was employed.

To observe the magnetic condition of the specimen, it was surrounded by a secondary coil of the same wire, wound on a silica tube, this tube being inside that supporting the primary winding. Side by side with this secondary coil was a similar one, and both were connected in series, but magnetically opposed, with a ballistic galvanometer. With no magnetic material in the furnace, making or breaking the magnetising current produced no kick in the galvanometer, whether the furnace heating current was on or off. With the specimen inside one of the secondary coils, the magnitude of the kick of the galvanometer, when the magnetising circuit was opened or closed, was therefore proportional to its magnetic induction for a field of 15 c.g.s. In this way, during the heating and cooling of the specimens, a series of observations was made and plotted, resulting in the curves shown in broken lines in the diagrams. For each material the temperature of loss and regain of magnetism was in this way determined with sufficient clearness.

A further indication was obtained by applying a hand-magnet in the following way. To prevent the magnet from being unduly heated, its poles were extended by soft iron rods clamped on. In making a test the magnet was balanced on the fingers, and the extended pole tips quickly applied to the test specimen in the furnace. Care was taken to avoid prolonged application, and consequent cooling of the specimen. With practice the loss of magnetism on heating and its return on cooling could be detected by the 'feel' of the magnet. It was found that clearer observations could be made with the (alternating) furnace current kept on than if it were temporarily switched off. The temperatures of the magnetic changes determined by this hand-magnet test are also shown in the diagrams. They are obviously not so reliable as those determined by the induction method. In general, the temperatures indicated by the magnet are rather lower, no doubt owing to a larger degree of magnetisation being necessary to affect it. For the determination of the induction curves

the rate of heating and cooling was five seconds per $1^{\circ}\text{C}.$, and for the hand-magnet tests ten second per $1^{\circ}\text{C}.$ The maximum temperature in both cases was about $810^{\circ}\text{C}.$

Dealing first with the loss of magnetic qualities on heating (Figure 16), the temperature at which this occurs seems to be very little influenced by the percentage of manganese. For each of the magnetic specimens—that is, up to and including E/3 with 14.30 per cent manganese—it occurs within the range from 765° to $780^{\circ}\text{C}.$

Turning to the inverse rate curves, specimen 1727D with 0.06 per cent manganese gives clear indications of the Ac_2 and Ac_3 points, although the carbon change point Ac_1 does not appear.

In the case of 1379A and B with 1.68 and 3.95 per cent manganese, respectively, only one point appears clearly, though a slight but definite protuberance seen in the curves—the existence of which was confirmed on repetition—seems to indicate a further transformation for each material. The upper of these two transformations appears to be the Ac_3 change, progressively lowered from 903° to 802° , with increase in manganese from 0.06 to 3.95 per cent. The lower transformation similarly corresponds to the Ac_2 magnetic change, its completion, so far as ascertainable from the inverse rate curve, agreeing reasonably well with the observed loss of magnetism.

In specimens C/2 and D (6.75 and 9.45 manganese) there is only evidence of one transformation. As the end-point of this transformation (752° and 720° respectively), so far as it can be determined, is below the temperature of loss of magnetism (770°), the two points Ac_2 and Ac_3 have presumably now combined. This being so, the retention of magnetism in these specimens in a small range of temperature above what appears to be the completion of the thermal transformations is peculiar. Similar behaviour is, however, observed in the cooling curves referred to below.

Specimens E and E/3 with 12.95 and 14.30 per cent manganese, although possessing initially sufficient magnetism for the magnetic transformation temperature (770°) to be

determined, show no corresponding indication in their inverse rate curves. E/3, however, displays a critical point at as low as 264°. On repetition a similar point was found at 230°.

Specimens G and J (17.10 and 61.50 per cent manganese) are devoid of critical points in their inverse rate curves, and as might be expected G, initially non-magnetic, gave no indications of magnetic changes.

The appearance of a critical point in specimen I (83.50 per cent manganese), apparently quite unconnected with those observed in the alloys containing the lower percentages of manganese, is interesting. Its actual nature has not so far been examined, though possibly it has its origin in some transformation occurring in the metal manganese itself on heating.

On cooling (Figure 17) the first reappearance of magnetism again occurs at practically the same temperature (767° to 776°) for all the magnetic alloys, and very nearly the same as that at which magnetism disappeared on heating.

In the alloys up to 3.95 per cent manganese, the magnetism reaches practically its full value after a further slight fall of temperature, and remains more or less constant down to room temperature. With 6.75 per cent manganese and above, the magnetism after reaching a maximum falls off again with decreasing temperature until a second critical temperature is reached, at which there is a further recovery. This recovery is maintained and increased until, when room temperature is reached, the specimen has regained approximately its original magnetic value. The magnetic changes in these alloys are naturally smaller in magnitude generally than for the more magnetic alloys with less manganese, and diminish in strength as the manganese content increases.

This second and lower critical magnetic change point appears in alloy C/2 (6.75 per cent manganese) at 315°, and is progressively lowered with increase in manganese to about 100° in alloy E (12.95 per cent manganese), becoming at the same time much weaker. In alloy E/3 (14.30 per cent manganese) no such critical point is discernible. This is only to be expected in view of the feebly magnetic qualities of the material. It is interesting to note that this material

E/3, although never displaying magnetism to a high degree, is more strongly magnetic at about 600° than at room temperature.

Specimen G (17.10 per cent manganese) gives, as on heating, no indication of magnetism at any temperature on cooling.

A noticeable feature in these magnetic determinations was the fact that this lower magnetic change point was not fixed, but in all cases on repetition appeared at a rather lower temperature. Thus in E (12.95 per cent manganese), during the cooling following the seventh heating, it appeared at 150°. In the eighth cooling the temperature was 100°. Check tests on specimen D (9.45 per cent manganese) with the hand-magnet gave 220° and 205° in the third and fourth coolings respectively, while with C/2 (6.75 per cent manganese) the temperatures were 300° and 295° in the fifth and sixth coolings.

For this reason the serial number of each heating and cooling is indicated against all the curves in the diagrams. Whether such alteration is due to a physical change caused by repeated heating, or to a reduction by oxidation in the already small carbon content, has not yet been investigated. No such variation occurs in the position of the upper magnetic transformation, which remains fixed at very nearly the same temperature with repeated heating. Thus with specimen E (12.95 per cent manganese) in the eighth cooling, in which the lower magnetic change had shifted through 50°, the upper magnetic change was found at 770°, as in the seventh cooling.

As regards the cooling curves of the inverse rate type, that for 1727D (0.06 per cent manganese) displays the three critical points Ar_2 and Ar_1 . 1379A (1.68 per cent manganese) only displays one critical point, corresponding with the reappearance of magnetism. None of the curves for the remaining magnetic alloys, *i.e.* up to E/3 (14.30 per cent manganese), gives any indication on the inverse rate curve of this upper magnetic transformation.

With the appearance of the lower magnetic change point in C/2 (6.75 per cent manganese) and the magnetic alloys of higher manganese content, a corresponding evolution of heat appears in the inverse rate curves, diminishing in intensity with increase of manganese. For E/3 (14.30 per cent manganese) this evolution was discernible, although, as previously mentioned, the magnetic change could not be detected. In the non-magnetic specimen G (17.10 per cent manganese) the evolution of heat has also disappeared.

Specimen I (83.50 per cent manganese) undergoes an evolution of heat at 710° , evidently corresponding with the absorption already noted in the heating curve.

The curve for D shows a curious doubling of the heat evolution, which it will be noted is also slightly but definitely reflected in the curve of magnetism.

Returning to B (3.95 per cent manganese), a single evolution of heat takes place at about 500°C . This seems to take its place in a regular progression as regards temperature between the Ar_3 point of the initial material and the heat evolutions in the remaining alloys. Ordinarily it would be regarded as the Ar_3 point, which has brought down the A_2 change, or in this case a portion only, with it. There is no sign, however, in the corresponding curve of any change in the magnetic condition accompanying this heat evolution. In these circumstances it is somewhat difficult to define in the usual terms the nature of the heat evolution seen in these cooling curves. The magnetic behaviour of these alloys of iron and manganese during heating and cooling is, in fact, so interesting and unusual as to justify further investigation.

It seems clear, however, from these observations that the loss of magnetism which occurs when the manganese reaches about 16 per cent is the culminating point of a progressive reduction in the magnetic quality with increase of manganese—not merely as found at ordinary temperature, but at all temperatures.

It has been too readily assumed by some writers that the magnetic transformation, in its downward course with increasing manganese, passes below atmospheric temperature; hence the alloys with manganese percentages above that at which this occurs are naturally found at ordinary temperatures

to be non-magnetic. On the contrary, as was shown in the joint research referred to by Onnes, Woltjer, and the author, this explanation cannot be correct, since no evidence of transformations below ordinary temperature was found, that is, for iron-manganese alloys. With iron-nickel alloys, on the other hand, magnetic transformations did occur on immersion in liquid air.

In the present research it seems clear that the magnetic strength of the alloys becomes progressively weaker with increase of manganese, and the final transformation also as a consequence diminishes in intensity, finally vanishing before 17.10 per cent manganese is reached, and also before this transformation has reached ordinary temperature.

Section 10.—Photomicrographs

Micro examination of each of the alloys up to and including 38.9 per cent manganese was carried out on the forged material in the conditions both 'as forged' without further heat treatment, and also after quenching in water from 1,000°C. The specimens were in the form of $\frac{1}{4}$ -inch-square bars, and micro examination was made of a transverse section.

Representative microstructures are reproduced in Figures 18 to 29 from micrographs taken at a magnification of 600, and the general type of structure exhibited by the different alloys is indicated also in Table XVII.

In Table XVII the microstructures have been described according to the conventional classification—pearlitic, martensitic, and austenitic. Exception may perhaps be taken to the use of the term pearlitic, as describing a microstructure which consists principally of ferrite. The term 'pearlitic' is, however, used here to indicate that the carbon is present as visible carbide instead of being in solution, as it is in martensitic and austenitic structures. Since in the alloy steel 'A' there is only 0.07 per cent of carbon present, there can be but little pearlite, and as is usual with material in which the carbon is very low, some of the ferrite of the few pearlitic aggregates has merged with the main ferrite, leaving free cementite.

Table XVII.—Microstructure of Iron-Manganese Alloys with Low Carbon

Mark	Analysis		Brinell hardness		Type of microstructure	
	Carbon. Per Cent	Man- ganese. Per cent	As forged	Quenched in water from 1,000°C.	As forged	Quenched in water from 1,000°C.
1379/A	0.07	1.68	155	211	Pearlitic	Martensitic
1379/B	0.06	3.95	277	325	Pearlitic and troosto-marten- sitic	"
1379/C	0.06	6.68	360	373	Martensitic	"
1379/D	0.07	9.45	420	402	"	"
1379/E	0.09	12.95	334	314	"	"
1379/E3	0.14	14.30	288	277	"	"
1379/G	0.15	17.10	250	229	Austenitic and martensitic	Austenitic and martensitic
1379/F	0.08	22.70	220	216	Austenitic with traces of mar- tensitic	Austenitic with traces of martensitic
1379/H	0.20	38.90	204	181	Austenitic	Austenitic

Confining attention to the series as forged, except where otherwise mentioned, the actual structure of specimen A with 1.68 per cent manganese consists of ferrite with small quantities of pearlite and free cementite, partly spheroidal, in the grain boundaries.

Specimen B with 3.95 per cent manganese is interesting, because on exploration under the microscope some of the fields resemble those of specimen A, while others are troosto-martensitic, that is, the martensitic needles etch darkly.

The structure of B thus consists of ferrite, pearlite, and spheroidal cementite in parts, with numerous troosto-martensitic areas. Evidently this particular composition represents or approximates to the boundary between the pearlitic and martensitic steels of this series.

The structures of C, D, E, and E3 are wholly martensitic; Specimen G, containing 17.10 per cent manganese, is the steel with the lowest proportion of that metal which shows

any austenitic structure in the series. This is the case both in the condition as forged and also after quenching in water from 1,000°C.

The present series of steels, therefore, in displaying first a pearlitic range, then a martensitic, and finally a range in which an austenitic structure is present, confirms the results obtained in this respect by other investigators. It may be of interest to make a more detailed comparison in certain cases. Obviously the points of importance are: (*a*) the composition at which the structure becomes martensitic; and (*b*) that at which an austenitic structure first appears.

Taking the various published researches on this series in the order of their publication, the well-known diagram of Dr. L. Guillet would place (*a*) at about 6 per cent and (*b*) at about 12.5 per cent manganese, that is, in steels containing 0.10 per cent carbon.

Dr. Jerome Strauss, in his paper "Characteristics of Some Managanese Steels" referred to previously, finds that a steel containing 0.03 per cent carbon and 5.88 per cent manganese is decidedly martensitic, while one containing 0.05 per cent carbon and 16.35 per cent manganese gives a mixed austenitic and martensitic structure.

Mr. Kasé finds that with a trace of carbon, 4 per cent manganese gives ferrite, while the 6 per cent alloy is martensitic. He states that 15 per cent manganese yields a martensitic structure, while the 20 per cent alloy yields an austenitic structure.

While in each of these cases quoted no heat treatment had been given, the material being in either the 'as cast' or the 'as forged' condition, or 'normalised' or cooled in the (experimental) furnace, it is not easy to compare the actual rates of cooling from the data given. The rates, however, at any rate, obviously were not extreme, as are those brought about by quenching, or, on the other hand, by very slow cooling after annealing.

In the series prepared and examined by Arnold and Knowles, and containing under 0.1 per cent of carbon, micro-specimens were obtained from 1 inch round bars, heated to 860°C. and cooled slowly over three days. Arnold described the structure of the material containing 4.1 per cent

manganese in the following words: "Martensitic structure often well defined." This, of course, was a very slow cooling, and the fact of such a structure being formed here is noteworthy.

Unfortunately no indication is given by Arnold to enable the commencement of the austenitic structure to be fixed among the higher members of his series.

Consideration of these various results indicates again that the alloy containing 3.95 per cent manganese is near the boundary between the pearlitic and martensitic low-carbon manganese steels, thus agreeing with the deduction from the actual examination of the microstructure of the author's specimen B.

With reference to the limiting composition at which an austenitic structure is first found, in the slowly cooled series, this would appear to lie between the composition of E3 and that of G, in the author's series—that is, between 14.30 and 17.10 per cent. Strauss also, as has been mentioned, finds a mixed austenitic and martensitic structure with 16.35 per cent manganese.

Specimen G is of special interest, as it is in this alloy that almost completely non-magnetic qualities have been arrived at, and an austenitic structure appears. It is important to note that within many of the grains of this structure there are nevertheless many lines frequently arranged in geometrical patterns, having all the appearance of intersections of octahedra by the plane of the microsection, that is, a martensitic structure.

Even in the alloy F, containing 22.70 per cent manganese, there are still traces of this martensitic structure.

In the alloy H, however, with 38.90 per cent manganese, exhibiting clear etching grains, the structure is typically austenitic.

Section 11.—Corrodibility

For the purpose of determining the characteristics of this series of alloys as regards their resistance to corrosion, tests were carried out by exposure to (a) Sheffield tap water, (b) artificial sea-water, (c) atmospheric corrosion.

The author's previous experience, and the work of other investigators, had not made it appear likely that alloys of this character would exhibit any advantageous features as regards their resistance to corrosion, and therefore in this instance it was not considered necessary to investigate the whole series. Alloys B, E3, G, and H were selected for the purpose as covering the whole range in convenient stages.

In order that the results should be strictly comparable one with another, it was decided to carry out these tests on the material quenched in water from 1,000°C. rather than in the 'as forged' condition.

The procedure in the case of the tests in tap water and sea-water was simply to place the polished and weighed specimen, 12.5 by 2.6 by 0.4 centimetres in size, in a tall glass cylinder, so that it was only in contact at the ends with the base and side of the jar respectively. The liquid was then poured in until the whole of the specimen was well covered, 400 cubic centimetres being used. The liquor was changed every fourteen days, and the total exposure lasted for a period of three months. The artificial sea-water consisted of a solution of 3 per cent Tidman's sea-water in distilled water.

The specimens for atmospheric corrosion, after polishing and weighing, were suspended in the open with free access of air on all sides, in the Attercliff district of Sheffield, where the atmosphere is of an industrial character and contains an appreciable amount of sulphur dioxide.

At the completion of the test the specimens were cleaned in order to remove loose corrosion products, and reweighed. The loss of weight, expressed in grammes per hundred square centimetres of surface exposed, in the separate tests is shown in the following table:

Table XVIII.—Iron-Manganese Alloys with Low-Carbon—Corrosion in Various Media.

Mark	Carbon Per cent	Manganese Per cent	Loss by corrosion. Grammes per 100 sq. cm.		
			In tap water. Three months	In sea-water. Three months	In atmosphere. Twelve months
B	0.06	3.95	0.75	0.66	6.30
E3	0.14	14.30	0.76	1.10	3.00
G	0.15	17.10	0.76	0.96	2.80
H	0.20	83.90	0.80	0.97	2.80

The results in Table XVIII show that no alloy of this series appears to possess useful corrosion-resisting properties. At the same time, the alloys containing 14 per cent manganese or over, only suffer in an industrial atmosphere about one-third of the corrosion sustained by ordinary mild carbon steel, or about three times that of rustless iron or steel of the simple high chromium type, as determined in tests carried out under comparative conditions.

Section 12.—Discussion of the Results

Examination of this series of iron-manganese alloys so far as their qualities have been investigated, has not indicated that any of the series has really valuable or useful qualities for industrial applications. The special qualities called for in industry are now, however, so many and varied that it is impossible to say that a particular alloy or material may not eventually find a special use for which it is better fitted than any other.

The results obtained have proved most useful in helping towards an explanation of the special qualities of manganese steel—that is, the alloy containing about 13 per cent of manganese with 1.25 per cent of carbon—which make this material so serviceable for many purposes.

It is evident that one characteristic property of manganese steel, namely, non-magnetism, has its origin in the association of the iron and manganese, since it is quite possible to obtain non-magnetic qualities by the use of these two elements alone.

Carbon, however, is not without its effect in this connection, and, in fact, the present research shows that in the practical absence of carbon, manganese steel containing 12 to 13 per cent manganese would be quite strongly magnetic even in its water-quenched condition—namely, about 12 per cent specific magnetism, compared with pure iron as 100. The presence of carbon, in fact, enables non-magnetic qualities to be obtained with much lower percentages of manganese than otherwise. While in the iron-manganese alloys practically free from carbon at least 16 per cent of manganese is necessary,

the author has by the addition of 1 per cent of carbon obtained non-magnetic qualities in alloys containing as low as 7 per cent manganese.

Carbon also influences over a certain range of manganese percentage the degree of permanence of the non-magnetic qualities under the influence of heat treatment, and it is in fact the prime cause of the development of magnetism in manganese steel by heat treatment. Iron-manganese alloys in the absence of carbon are, on the other hand, apparently not influenced in their magnetic character by heat treatment. This has been fully discussed in the section dealing with magnetic and electrical qualities.

In respect of electrical resistance, we are now familiar with a variety of alloys having a high electrical resistance up to as much as 130 microhms per cubic centimetre, and the possession of an electrical resistance of 87 microhms per cubic centimetre in these iron-manganese alloys, depending on the manganese percentage, although at one time this might have been considered remarkable, does not provide any new feature of value.

It is further evident that the special features of manganese steel as regards its mechanical qualities, namely, its high tenacity combined with extraordinary ductility, and a remarkable propensity for hardening under deformation, also have their basis in this iron-manganese combination, although such alloys do not display these qualities to the same enhanced degree as manganese steel, and require a considerable higher percentage of manganese. The presence of carbon to the amount of 1.25 per cent adds very considerably to the tenacity, also to the ductility and work-hardening qualities, and further enables alloys of comparatively low percentages, *i.e.*, even down to 4 or 5 per cent, to display such characteristic qualities to an appreciable degree, although not to the same extent as manganese steel properly so called, that is, the alloy with 13 per cent manganese.

The researches of Guillet, Arnold, Kasé, and the author have now very well established the mechanical qualities of the iron-manganese series of alloys in their main features. Of these, apart from the qualities above referred to which are exhibited above 16 per cent manganese up to at any rate

39 per cent, the most marked feature is the comparative brittleness of the alloys containing from about 4 to 10 per cent manganese with a maximum of brittleness at about 7 per cent. Material with this percentage, while possessing quite appreciable hardness and cohesion, is incapable of much deformation, and, further, the nature of the cohesion is such that it is apparently easily influenced by small factors. What these factors are is not at present known. On either side of 7 per cent, the alloys partake of this character, more or less according to their proximity in composition, but finally merging into the characteristics of high tenacity and ductility previously referred to at the higher percentage, and, on the other hand, towards the low tenacity and comparatively high ductility of iron itself at the lower percentages.

In the author's original research on alloys of iron, manganese, and carbon, in which the carbon percentage in relation to that of manganese was approximately as 1 to 10, a somewhat similar characteristic, that is, of hardness and brittleness, was specially noted, *i.e.*, at what was then known as the brittle percentage containing about 5 per cent manganese. This particular alloy containing about 0.5 per cent carbon was so brittle that it could easily be pounded with a hand-hammer, its hardness being over 600 Brinell, sufficient to scratch glass. Here again the brittleness of this alloy appears to be connected with a similar brittleness found, although in not so marked a degree, in the alloys of iron and manganese with low carbon content containing from 4.00 to 10.00 per cent manganese. While the presence of carbon undoubtedly adds to the hardness and brittleness in such alloys of comparatively low manganese percentage, this characteristic is evidently derived mainly from the combination of the iron and manganese.

Section 13.—Conclusion

In summing up the general results of the present research, and in comparing the physical properties of the materials described, one of the features of outstanding importance is undoubtedly that they bring out very clearly the literally marvellous influence of carbon.

On consideration, it is not a little astonishing to find that the production of the valuable material known as manganese steel, which the author discovered in 1882 and described before this Institute in 1888, would probably not have been possible had the ferro-manganese used in his researches contained a low percentage of carbon; 80 per cent ferro-manganese ordinarily contains 6 to 7 per cent carbon.

The result of the present research clearly shows that alloys of manganese without carbon do not appear to be of commercial value. There may be applications here and there for some of the materials, but as far as at present ascertained, characteristics or qualities which indicate value from the industrial point of view have not been found.

Ferro-manganese as ordinarily produced contains a ratio of about one-twelfth of carbon to manganese in 80 to 84 per cent ferro-manganese. Consequently in the manufacture of manganese steel there must always be about 1 to $1\frac{1}{4}$ per cent of that element present in the steel produced, which is one of the chief reasons for its valuable properties.

At the time of the author's discovery, the experiments and researches he made were carried out with ferro-manganese of the type then produced by Mr. Pourcel. Thus the manganese steel produced contained the quite considerable percentage of carbon mentioned. Take away that percentage of carbon and the product becomes of little or no value. It will thus be seen that fortunately this valuable product, ferro-manganese, was available for the author's early research work in 1882 to 1890 on alloys of iron and manganese, otherwise his immediate research at that time would probably not have resulted in anything more than products of academic value. Therefore, ferro-manganese, with its one-twelfth ratio of carbon, is a valuable blast-furnace product, not only because of the manganese in it, but also the carbon. Once more is shown the wonderful nature and value to the metallurgist—in fact, to the human race generally—of the element known as carbon.

In such cases also as high-speed steel and many others an appreciable percentage of carbon is absolutely essential to their character. Singularly enough, and in contradistinction to this, it has been and is being found that certain other alloys

of iron, if containing carbon in any quantity, say about 0.50 per cent and upwards, are not nearly so valuable as when the carbon is reduced to the lowest possible point, say 0.10 per cent, and even under.

The silicon steel which the author described to this Institute in 1889 owes in part its valuable properties not only to the high percentages of silicon present but also to the low percentage of carbon. The modern chromium steel alloys are much better in their resistance to corrosion in the absence, or presence only in low percentages, of carbon. This, too, also applies to the new types of nickel-chromium steel-alloys.

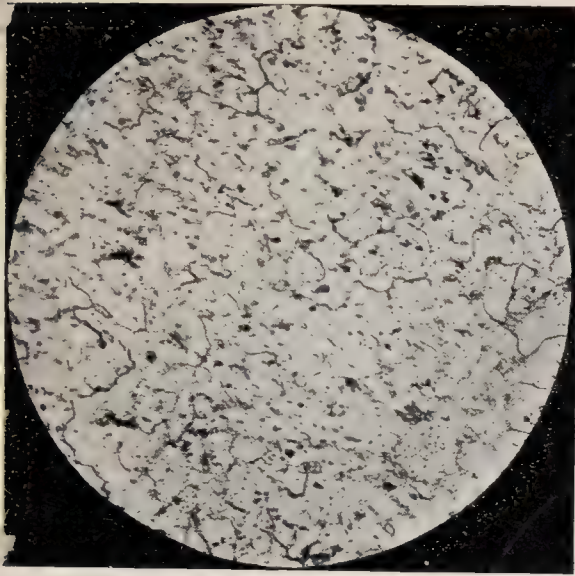
On the other hand, manganese-iron alloys with little or no carbon do not seem to offer any practical employment; they only become valuable in the presence of quite high percentages of carbon, 0.90 to 1.50 per cent.

It may be mentioned that in carrying out this research, there have been made 806 tests of various kinds, comprising mechanical, chemical, physical, metallographic and other tests, involving considerable time, labour and expenditure.

In conclusion, the author desires to thank those who have assisted him over a long period of time in carrying out this costly and laborious research. These include Mr. W. J. Dawson; Mr. S. A. Main; Mr. T. G. Elliott; Mr. W. J. Todd; and Mr. A. Stevenson. He trusts that the information presented may prove of general service, and that the research will be found to cover ground which had not before been fully explored.

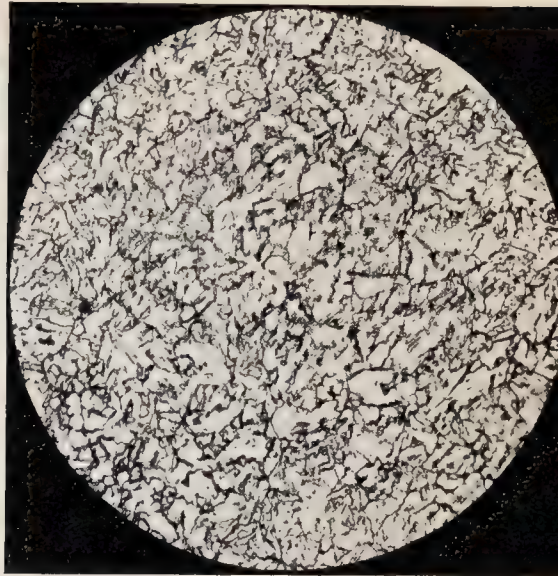
Specimens in the condition 'As Forged.'

Specimen A.
Micro. No. 4031. $\times 600$.



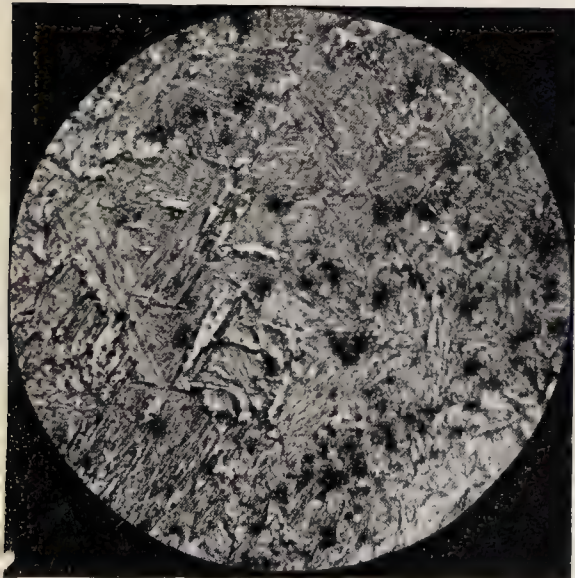
C 0.07; Mn 1.68 per cent.
Figure 18.—Ferrite, with small quantities of pearlite, and some cementite in the grain boundaries.

Specimen B.
Micro. No. 4033B. $\times 600$.



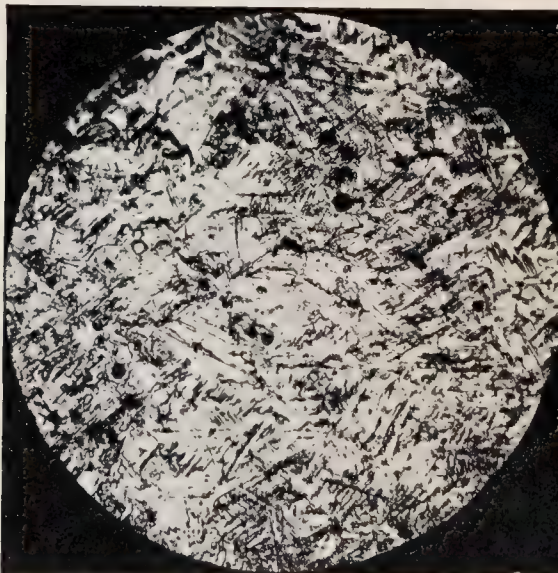
C 0.06; Mn 3.95 per cent.
Figure 19.—The micro-structure of this steel varies in different areas. This photograph represents the pearlitic areas.

Specimen B.
Micro. No. 4033. $\times 600$.



C 0.06; Mn 3.95 per cent
Figure 20.—This photograph represents the troost-martensitic areas.

Specimen G.
Micro. No. 4045B. $\times 600$.



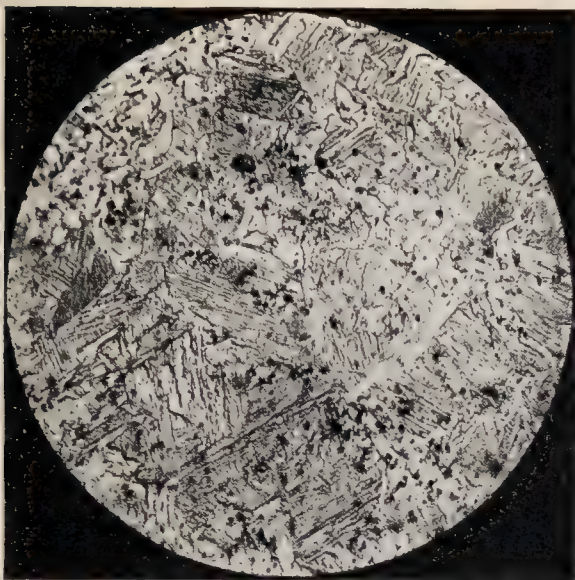
C 0.15; Mn 17.10 per cent.
Figure 21.—Mixed austenitic and martensitic structure.

Reduced by one-quarter.

Specimens in the condition 'As Quenched' from 1,000°C. in Water.

Specimen A.
Micro. No. 4032. $\times 600$.

Specimen B.
Micro. No. 4034. $\times 600$.



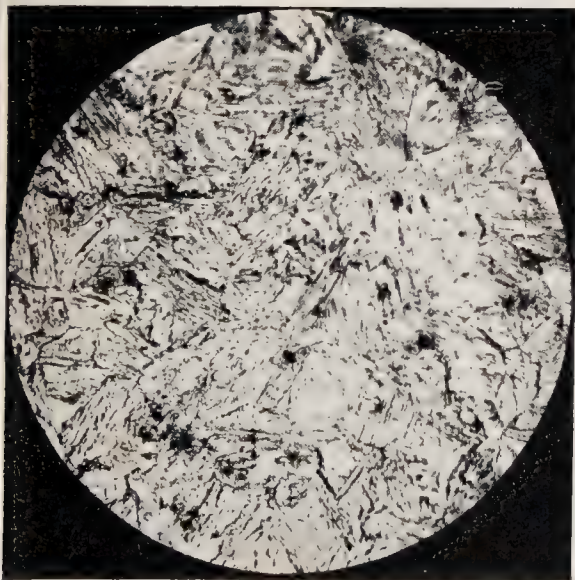
C 0.07; Mn 1.68 per cent.
Figure 22.—Martensitic structure.



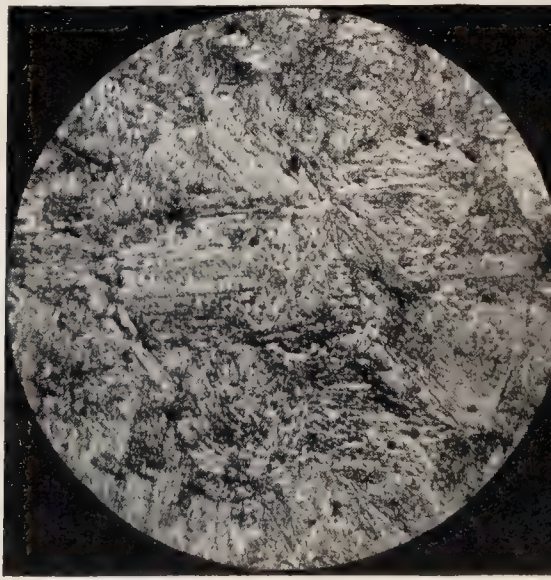
C 0.06; Mn 3.95 per cent.
Figure 23.—Martensitic structure.

Specimen C1.
Micro. No. 4036C. $\times 600$.

Specimen D.
Micro. No. 4040B. $\times 600$.



C 0.06; Mn 6.68 per cent.
Figure 24.—Martensitic structure.



C 0.07; Mn 9.45 per cent.
Figure 25.—Martensitic structure.

Reduced by one-quarter.

Specimens in the condition 'As Quenched' from 1,000° C. in water.

Specimen E3.

Micro. No. 4215B. $\times 600$.

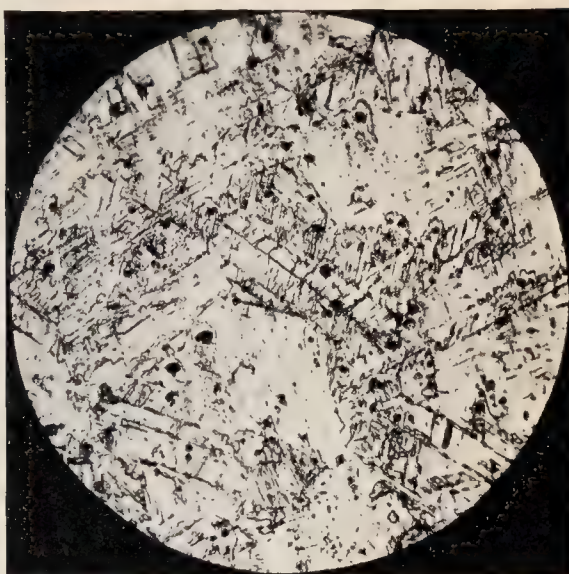


C 0.14; Mn 14.30 per cent.

Figure 26.—Martensitic structure.

Specimen G.

Micro. No. 4046C. $\times 600$.

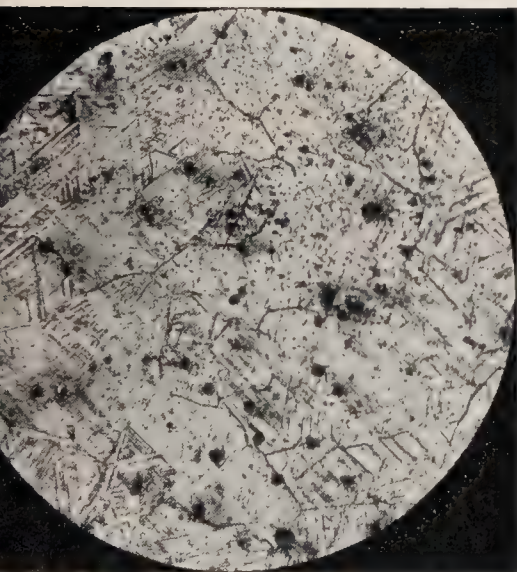


C 0.15; Mn 17.10 per cent.

Figure 27.—Mixed martensitic and austenitic structure.

Specimen F.

Micro. No. 4044. $\times 600$.

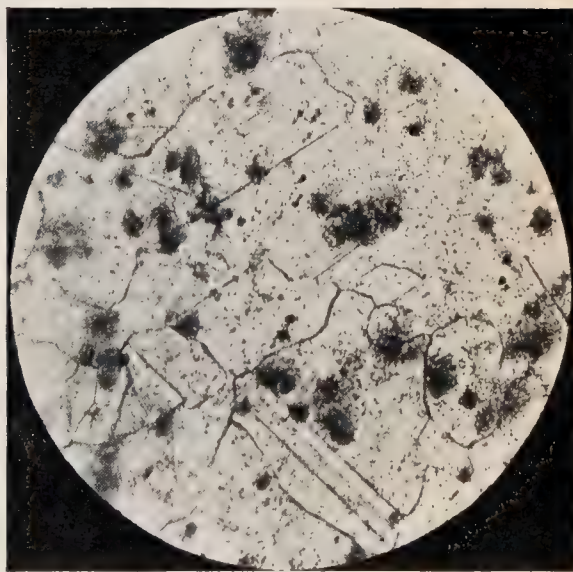


C 0.08; Mn 22.70 per cent.

Figure 28.—Austenitic structure with traces of martensitic.

Specimen H.

Micro. No. 4048. $\times 600$.



C. 0.20; 38.90 per cent.

Figure 29.—Austenitic structure.

Reduced by one-quarter.

INDIA'S RESOURCES IN RAW MATERIALS FOR A DOMESTIC IRON AND STEEL INDUSTRY

BY CYRIL S. FOX*

(*Member, Min. & Geol. Inst. of India.*)

(Sydney, N. S., Meeting, September 10th, 1927)

INTRODUCTION

In 1923, at the request of the Director of the Geological Survey of India, I drew up a report on the mineral resources of India for the domestic production of iron and steel. This report was intended to assist the Indian Tariff Board in their investigations regarding the grant of a subsidy to the Tata Iron and Steel Company, Ltd., who then represented the Indian steel industry. In preparing my report I accumulated a considerable amount of information which was incorporated in a paper ⁽¹⁾ and subsequently presented to the Mining and Geological Institute of India. A very interesting series of discussions ⁽²⁾ resulted from the publication of the paper. These contributions by members of the Institute, although largely concentrated on the subject of reserves of caking coal of a quality suitable for the production of metallurgical coke, nevertheless contained many valuable details, which, had they been in my possession earlier, might have made the paper referred to almost authoritative. Since then, further information has come into my possession as a result of surveys and researches in the Jharia, Raniganj, and Giridih coal-fields, and from information supplied by chemists and metallurgists during visits to the various coke-oven plants and smelters in and about these coal-fields. Instead, therefore, of being simply a compilation of facts from published papers and office files, the present paper supplies a fair quantity of first-hand information, largely based on local knowledge, of those particulars

*Geological Survey of India.

⁽¹⁾ "The Raw Materials for the Iron and Steel Industry of India"; *Trans. Min. Geol. Inst. India*, Vol. XX, Pt. 2, 1925, pp. 87-194.

⁽²⁾ *Op. cit.*, Pt. 4, 1926, pp. 331-422.

mentioned in my report to the Tariff Board, and in the paper to the members of the Mining and Geological Institute. Although the chief features of the statements made in these publications remain the same, there were many emendations I should like to have introduced in them since. In consequence of this, I submit this paper as a fairly up to date statement, as accurate as it is now possible for me to make it. It is my hope that this contribution on India's resources in raw materials for a domestic iron and steel industry will prove of interest at the meeting of Empire Mining Congress at which it is read, and to subsequent readers.

History

The discovery of rusted iron implements in burial urns and the study of other pre-historic remains have led archæologists to believe that a knowledge of iron smelting existed in India nearly 4,000 years ago ⁽¹⁾. At the time of the Greek invasion, in 326 B.C., Alexander was presented with 100 talents of steel by the chiefs of the Punjab. He had previously found the fighting peoples of the Indian North-West as familiar with the use of iron and steel as the Macedonians themselves. The well-known wrought iron pillar ⁽²⁾ at the Kutab, near Delhi, bears an inscription of the period A.D. 415 ⁽³⁾, and there are several relics, broken pillars ⁽⁴⁾, built up cannon ⁽⁵⁾, and the like, all made of wrought iron of an excellent quality, in various parts of India. Many of them carry Persian inscriptions of the time of Akbar or Aurangzeb. However, it is in the manufacture of steel that the early Indian smelters were justly famous. "The manufacture of 'wootz', or Indian Steel, anticipated the cementation process by many centuries...." and there "seems little doubt that it was from Indian crucible-

⁽¹⁾ Imperial Gazetteer of India, Vol. II, pp. 25 and 98. Also the Commercial Products of India, by Sir George Watt, p. 692.

⁽²⁾ "The pillar at Delhi weighs over 6 tons, is of solid wrought iron of excellent type, 23 ft. 8 in. in height, 16½ in. in diameter at its base, and 12 in. just below the capital. It is sunk into the ground for 20 in., and there expands into a bulbous form, 2 ft. 4 in. in diameter, resting on a grid of iron bars fastened with lead into a stone pavement".

⁽³⁾ A Sanscrit poem, the epitaph of the Gupta King Chandragupta II.

⁽⁴⁾ At Dhar, Central India, with Persian inscription of Akbar, A.D. 1591-2.

⁽⁵⁾ *The Nau Gaz Banduk* (nine-yard gun) at Narnala Fort, Akola District, Berar.

steel that the celebrated Damascus sword-blades were made”“the alloy from which they were fashioned was produced in obscure Indian villages, whence it was obtained by Persian traders”(1).

The Agarian Industry

Almost throughout the whole of last century, a small but flourishing indigenous iron industry existed in most districts in India (2). In some cases the industry was of appreciable size. In most places wrought iron was the only product obtained (3). The ore used varied from magnetic sands to hematitic-laterite. The fuel was always charcoal. No flux appears to have been intentionally added to the charge. The furnaces were invariably made of mud, and produced from a few pounds to a few cwt. of metal blooms a day. The Indian iron smelters form a distinct caste and are known as *agarias* (4). Agaria furnaces are still to be seen in operation in remote villages in several places. This industry has been slowly dying in the face of cheaply imported iron and steel (5). We, in the progress of our geological work, find old slag heaps in unexpected and long forgotten places, often in the vicinity of the sites of deserted villages. The tire of the village cart, the point of the wooden country plough, the jungle axe, and the grass cutter's sickle, are now seldom made of metal which was laboriously smelted in the shelter of trees on the outskirts of villages (6). The imported metal is cheaper and stands the wear and tear better than the malleable iron of the agaria. Yet, it is interesting to remember that Indian-made iron and

(1) "The Iron and Steel Industry of India", by J. Coggin Brown. *The Mining Magazine* for June and July, 1921.

(2) V. Ball, *Geology of India*, pt. III, 1881, pp. 335-416. Sir G. Watt, *Dictionary of the Economic Products of India*; Vol. IV, 1890, pp. 499-520.

Sir T. H. Holland and L. L. Fermor, *Quinquennial Reviews of Mineral Production in India*.

(3) Except in the Salem District of Madras, where 'wootz' steel was made, the Indian smelters never made any cast iron.

Sir T. H. Holland, *Iron Industries of the Southern Districts, Madras Presidency*; 1893, pp. 1-24.

(4) The blacksmiths also form a distinct caste and are known as *Lohars*.

(5) The imposition of a tariff on imported steel has sent the prices up, and this has rejuvenated the Agarian industry in many places.

(6) Messrs. Best & Co., of Pondicherry, have established the Eagle Iron Works at Kumardhubi. Here scrap iron is fused in a reverberatory furnace and rolled into bars and rods which are in great demand in the bazaars.

steel has long enjoyed a reputation for high quality. When the Britannia tubular bridge across the Menai straits was under construction, preference is said to have been given to the use of pure malleable iron of Indian origin.

Early European Efforts

As is well known, several attempts have been made to establish iron works in India at various times. The earliest efforts were by Motte and Farquhar in the Birbhum area, about 1779 to 1789, and these, after spasmodic endeavours, terminated with a final attempt by Messrs. Burn & Co. in 1875. Perhaps the most strenuous effort, one attended with great personal sacrifice, was that by Heath, when, with the assistance of Government, the Porto Novo Steel and Iron Company and the East Indian Iron Company were established on the Malabar coast in 1830 and ultimately closed down in 1867. Government also tried to establish iron works near Naini Tal (Kumaon), between 1862 and 1877, but were obliged to give up the attempt. The most historic undertaking was that which began as an experiment by Messrs. Jessop & Co. in 1839, near Barakar. The next stage was the erection of iron works at Kulti which were privately operated till about 1879, when Government supported the establishment for nearly ten years. In 1887, these works were handed over to the Barakar Iron and Steel Co. and re-modelled. This company later became the Bengal Iron and Steel Co. and are represented today as the Bengal Iron Co. at Kulti. In nearly every case, the failure was due to lack of sufficient supplies of suitable fuel; in some instances there was obvious mismanagement, and in Heath's case Government were not able to support the company indefinitely. With the discovery of coking coal of good quality in the Giridih, Jharia, and Raniganj coal-fields, the fuel difficulty for the Chota Nagpur region was finally removed. As a result of this discovery, the Kulti iron works was able to survive the normal fate of European efforts with charcoal as fuel. The Tata Iron and Steel Co. were started early in the present century, after the discovery of the vast deposits of high-grade hematite in Mayurbhanj and the adjacent area.

The work of the several firms who constituted the Bengal Iron Co., Ltd., in its earlier stages, together with the success that has crowned all these efforts, "mark", as Dr. Coggin Brown has said, "the establishment of modern iron metallurgy in the Indian Empire on permanent foundations". Although the Bengal Iron Co., Ltd., had "proved beyond question that pig iron could be made profitably in India", it remained for Mr. Jamsetji Nusservanji Tata, with the technical advice and assistance of Mr. C. P. Perin, of New York, and his associate, Mr. C. M. Weld, to realize the second step — the introduction of modern steel works and rolling mills in India. These investigations began about 1902, the Tata Iron and Steel Co., Ltd., was formed in 1907, and the plant had been erected by 1912.

The Existing Industry

At present, for purposes of sale, steel is only made by the Tata Iron and Steel Co. of Jamshedpur (formerly known as Sakchi). Details of the plant at Jamshedpur ⁽¹⁾, which is being added to from time to time, have been given so often that it seems unnecessary to repeat the information here. It is enough to say that in 1924 the output of pig iron from the blast furnaces at Jamshedpur was over 540,000 tons, and the furnace charges totalled:

Iron ore.....	865,332 tons
Coke.....	672,789 "
Dolomite.....	272,763 "
Limestone.....	75,898 "

Note.—A change in blast furnace practice is being instituted whereby only limestone will be used in future.

These ironmasters estimate a production of about 600,000 tons of pig iron in a normal year. It is impossible to describe briefly the vast scale on which operations are being conducted at Jamshedpur (see Appendix, p. 268). It may give an idea of the up-to-date nature of the plant if the output of a single furnace is compared with one of the mammoth blast furnaces operating in the United States.

⁽¹⁾ See J. Coggin Brown's article in *The Mining Magazine* for June and July, 1921; also the Quinquennial Reviews of the Director, Geological Survey of India.

Daily charge	Mammoth American furnace	'D' blast furnace, Jamshedpur.
Iron ore.....	800 tons	769 tons ⁽¹⁾
Coke.....	400 "	546 "
Limestone.....	160 " Dolomite	319 "
Pig iron output.....	400 "	480 "

The Bengal Iron Co. at Kulti ⁽²⁾, near Barakar, were not operating their blast furnaces for several months in 1925 and 1926, but are now smelting again. Their production of pig iron for foundry purposes is said to be capable of attaining a total of 150,000 tons a year (see Appendix). It is estimated that this would entail an assemblage of 270,000 tons of iron ore, 225,000 tons of coke, and 75,000 tons of limestone. It is not certain if this very efficiently managed company propose to restart the manufacture of ferro-manganese, or whether they intend to specialize in particular brands of pig iron.

The furnaces of the Indian Iron and Steel Co. are situated at Hirapur, near Asansol. They were blown-in in 1922, and commenced production of pig iron in 1923, but have not made any steel up to the present (see Appendix). Their plant is said to have been designed for an annual production of 250,000 tons of pig iron, which would require some 440,000 tons of iron ore, 375,000 tons of coke, and 125,000 tons of limestone.

In all the above cases, a certain percentage of manganese ore appears to constitute an ingredient of the furnace charge. In every case, the coke is made at the respective works, the necessary coal being normally obtained from one or other of the valuable caking coal seams in the Jharia coal-field. The metallurgists at Jamshedpur and Kulti have utilized the low-phosphorus coking coals of Giridih for special purposes, and the Bengal Iron Co., as well as the State Railway Collieries at Giridih, have conducted work-scale experiments on the Rani-ganj coal-field caking coals. In all these smelting centres, there appears to be a slight variation from time to time in the kinds or blend of coals used for making their metallurgical

⁽¹⁾ The iron-ore charge is a little lower than in the American furnace owing to the purity of the ore, but taken all round the 'D' furnace has the larger capacity.

⁽²⁾ See page noted previously in *The Mining Magazine* for 1921.

coke. Similar changes in the source of supply or quality of the limestone and dolomite used for flux purposes is, to a lesser degree, also evident.

In addition to the above-named iron smelters in the region of the Bengal coal-fields ⁽¹⁾, mention must be made of others. A small plant was erected at Rupnarainpur, about 15 miles northwest of Asansol. These, Kirthyanand, works have never supplied metal for commercial purposes and the company has gone into liquidation. The Mysore Government have erected a plant ⁽²⁾ at Benkipur, in Mysore State, for the production of charcoal pig iron, which is finding a sale in Europe. An effort is being made here to produce wood alcohol and calcium acetate of commercial quality from the distillation products obtained in preparing the charcoal. The projected works of the United Steel Corporation of Asia remain a paper scheme. It was stated that a site for these works had been selected at Manharpur, close to the Pansira Buru (Kolhan) iron ore deposits. The proposed plant is reported to aim at an annual output of 700,000 tons of pig iron, and the employment of 1,250,000 tons of iron ore, 1,050,000 tons of coke, and 35,000 tons of limestone ⁽³⁾.

It was anticipated that by 1928 the capacity of the existing and seriously projected iron works in India would be capable of an annual production of 1,500,000 tons of pig iron requiring a supply of

2,650,000 tons of iron ore,
2,250,000 tons of metallurgical coke, and
750,000 tons of limestone.

The coke percentage of Jharia caking coals ⁽⁴⁾ is considered to average about 60 in normal practice, ranging from over 70 to as low as 40 per cent. This would mean the employment of about 4,000,000 tons of good quality coking coal for metallurgical purposes in the smelting of iron ore only.

⁽¹⁾ The name 'Bengal coal-fields' is a convenient expression to include the coal-fields of the Damuda valley, *e.g.*, Jharia and Raniganj, as well as Giridih.

⁽²⁾ The Bhadravati iron works are said to have an output capacity of 20,000 tons of charcoal pig iron annually.

⁽³⁾ Based on an ore charge of 34 cwt. (60 per cent Fe) hematite ore, 30 cwt. good quality Indian metallurgical coke, and 10 cwt. of Bisra limestone, for 20 cwt. of pig iron.

⁽⁴⁾ These include all varieties of coke — from metallurgical coke to the wastefully-made soft coke for bazaar sales.

INDIAN PRODUCTION OF IRON AND STEEL

(tons)

	1920	1921	1922	1923	1924	1925
Pig iron						
Tata Iron & Steel Co...	221,608	281,541	227,683	392,135	540,140	563,160
Bengal Iron Co.....	95,585	85,106	88,004	119,379	147,733	52,674
Indian Iron & Steel...	...	...	...	77,980	168,249	247,500
The Mysore Iron Works	...	...	...	9,732	16,425	16,741
Iron castings						
Bengal Iron Co.....	31,042	31,796	25,821	33,627	27,045	35,238*
Blooms, blooming mill						
Tata Iron & Steel Co...	137,232	158,101	135,151	178,987	(a)	(a)
Steel ingots						
Tata Iron & Steel Co...	156,239	182,690	150,475	187,974	218,472	309,938
Ferro-manganese						
Tata Iron & Steel Co...	1,183	3,076	1,810	3,506	8,951	6,527

*Includes railway sleepers and pipes, 29,327 tons.

(a) Not available.

Indian Imports of Iron and Steel

In his evidence to the Tariff Board, which has since been published in pamphlet form, Mr. George Pilcher has discussed very ably various aspects of the imports of iron and steel goods into India, and has thrown considerable light on other matters connected with the proposed protective tariff on steel products of certain kinds which are largely consumed in India. However, from the 'Accounts Relating to the Seaborne Trade of British India', I find that, excluding manufactured goods, such as millwork and machinery, and neglecting the trifling re-exports of semi-fabricated iron and steel products, such as iron bars, steel ingots, etc., India's imports of iron and steel for manufacturing purposes during the last six years have been as follows:

Year	Iron including pig iron, angles, bars, bolts, channels, etc.	Iron and Steel such as beams, gird- ers, rivets, bolts and nuts, rails, plates, tubes, pipes, wire, etc.	Steel including angles, bars, ingots, blooms, billets, tool-steel, etc.
1920.....	Rs. 91,88,940 31,481 tons	Rs. 2,045 lakhs 474,984 tons	Rs. 612.75 lakhs 192,795 tons
1921.....	Rs. 66,59,975 27,185 tons	Rs. 1,932.5 lakhs 389,826 tons	Rs. 408 lakhs 148,295 tons
1922.....	Rs. 81,72,662 46,420 tons	Rs. 1,507.5 lakhs 499,235 tons	Rs. 353.25 lakhs 203,497 tons
1923.....	Rs. 34,08,948 19,374 tons	Rs. 1,509.9 lakhs 585,745 tons	Rs. 296.93 lakhs 198,091 tons
1924.....	Rs. 27,74,489 15,348 tons	Rs. 1,620.39 lakhs 662,338 tons	Rs. 353.06 lakhs 255,362 tons
1925.....	Rs. 23,32,823 12,433 tons	Rs. 1,469.09 lakhs 627,707 tons	Rs. 176.17 lakhs 146,403 tons

The average total value of these materials is very little less than 22 crores of rupees, that is, nearly equal to 14½ million pounds sterling. The total assessed value of the property of the Tata Iron & Steel Co., including iron and steel plant, iron ore workings, collieries, and limestone quarries, is said to be about 22 crores of rupees — equal to the value of a certain class of imported iron and steel products which are absorbed in India in a single year.

Mineral Production

The appended table shows the annual Indian production of those minerals and ores which are commonly used in the metallurgy of iron and steel. Some of these substances are similarly used in India, but the majority of them are either used domestically for other purposes than steel making, or are exported to meet the requirements of the iron and steel industries of Europe and America.

Indian Mineral Production

In long tons (2,240 lb.)

Year	Iron ore	Coal	Mangan- ese ore	Wol- fram	Chro- mite	Mag- nesite	Tin ore (a)	Zinc ore (b)
1911	366,190	12,715,534	670,290	1,308	3,804	3,490	97	..
1912	580,224	14,706,339	633,080	1,671	2,890	15,379	175	..
1913	370,845	16,208,009	815,047	1,688	5,676	14,086	171	..
1914	441,574	16,464,263	682,898	2,244	5,888	1,680	214	..
1915	390,339	17,103,932	450,416	2,457	3,767	7,450	289	..
1916	411,809	17,254,309	645,204	3,692	20,159	17,640	465	..
1917	413,356	18,212,918	590,813	4,542	27,061	18,202	666	..
1918	492,669	20,772,493	517,953	4,431	57,769	5,853	780	..
1919	563,750	22,628,037	537,995	3,525	36,439	17,126	1,569	..
1920	558,005	17,962,214	736,439	2,346	26,801	14,346	(c) 2,118	750
1921	942,084	19,302,947	679,286	898	34,762	20,017	1,702	4,000
1922	625,274	19,010,986	474,401	943	22,777	19,273	1,875	18,061
1923	804,384	19,657,778	695,055	872	54,242	19,436	1,996	2,062
1924	1,445,313	21,174,284	803,006	739	45,462	24,461	1,880	16,650
1925	1,544,578	20,904,377	839,461	772	37,452	29,620	2,308	16,810

(a) Block tin output not included. (b) Export quantities only. (c) Excludes 1,223 tons of low-grade ore.

Literature

In his Annual Reports on Mineral Production, and in the Quinquennial Reviews, the Director of the Geological Survey of India makes public announcements on the mineral industry of India. Similar information for British India only is issued by the Chief Inspector of Mines. Much valuable technical information appears in the *Proceedings* of the Mining and Geological Institute of India. A summary of all the known mineral occurrences in India will be found in 'An Annotated Index of Indian Minerals of Economic Value', by T. H. D. La Touche. *The Mining Journal*, of May 13th, 1922, contains an article on 'The Trend of the Mineral Industry of India'. Among the more specialized articles may be mentioned: 'The Iron Ores of Singhbhum and Orissa', by H. C. Jones (*Rec. Geol. Surv. India*, LIV, 2, 1922); Iron Ore, Part IV,

British Asia, 1922 (a brochure by the Imp. Min. Res. Bureau); 'The Coalfields of India', by V. Ball and R. R. Simpson (*Mem. Geol. Surv. India*, XLI, 1, re-printed 1922); 'The Mineral Resources of Bihar and Orissa', by L. L. Fermor (*Rec. Geol. Surv. India*, LIII, 3, 1922); 'The Mineral Resources of the Central Provinces', by L. L. Fermor (*Rec. Geol. Surv. India*, L, 4, 1919); the brochure on 'Coal, Coke and by-Products', Part II, 1922, by the Imp. Min. Res. Bureau; 'Metallurgical Industries in India', by L. L. Fermor (Indian Munitions Board Handbook 1919, pp. 123-144); 'The Iron and Steel Industry of India', by J. Coggin Brown (*The Mining Magazine* for June and July, 1921); the recently published evidence of G. Pilcher before the Indian Tariff Board, etc. The evidence collected by the Tariff Board, as well as their report, constitute valuable publications on the subject of the Indian Iron and Steel Industry. There is a very useful résumé of the 'Developments in Modern Blast Furnace Practice' in the leader of *The Mining Journal* for December 15th, 1923.

Chief Raw Materials

I have found it convenient in the present paper to discuss the several raw materials of the iron and steel industry under the following headings:

1. Iron ores.
2. Coking coal.
3. Other coals.
4. Fluxes.
5. Modifying metals.
6. Refractory materials.
7. Subsidiary minerals.

A word of explanation with regard to the above groups of mineral substances is perhaps necessary. To assist a non-technical reader, I have prepared a flow-sheet (Plate I) in which is shown the various processes involved, the raw materials utilized, and the products obtained in the smelting of iron ores and the preparation of special steels. A metallurgical expert may find it too rigid, but I have aimed at simplicity and my purpose will have been served if the arrangement makes things clear.

The location of the most important iron ore deposits, coalfields, limestone occurrences, etc., and deposits of manganese ore, chromite, silica, fireclay, and apatite, are shown on the accompanying *mineral maps* (Plates II and III).

IRON ORES

It is only during the past few years that conclusive proof has been obtained to show that India possesses extremely valuable deposits of iron ore which had not previously been included in the estimates of the world's reserves. The chief interest centres about the great deposits of high-grade hematite in the 'Iron Belt' of Bihar and Orissa. These ores are purer in quality and occur in larger quantities than the Lake Superior ores of Minnesota, Wisconsin, and Michigan. Already the names Kolhan, Mayurbhanj, and Keonjhar are becoming as familiar in iron and steel industrial circles as those of Mesabi, Wabana, and Lorraine. For many years to come questions regarding reserves of Indian ore for smelting purposes will be concerned only with these hematite ores. The local government are reported to have allotted ore-areas to various companies on a basis of a hundred years' supply to each. The future requirements of the companies who have acquired leases were said to be:

Tata Iron & Steel Co.....	4,000,000 tons a year
Bengal Iron Co. Ltd.....	1,000,000 " "
Indian Iron and Steel Co.....	2,190,000 " "
United Steel Corporation of Asia.....	1,120,000 " "
Villiers, Ltd.....	2,000,000 " "
Total.....	10,310,000 " "

This means that there should be at least 1,000 million tons of reserves to meet a hundred years' supply at the above annual consumption. In the estimates for the anticipated pig-iron production of 1928, it was shown that the iron ore requirements would only be of the order of 2,650,000 tons. In the accompanying table of the quantity and quality of various Indian iron ores, it is seen that the estimates approach nearly 3,000 million tons in the iron belt. It has been stated

FLOW SHEET

IRON ORE

The principal iron ores are Magnetite, red and brown Hematite, and Spathic ores, clay ironstone, etc. These ores seldom require any preliminary treatment. They are cleaned occasionally and sometimes calcination is necessary. Ores containing more than 0.04% phosphorous yield a pig iron unsuitable for conversion into steel by the Acid Bessemer or Acid Open Hearth Processes.

FUEL

Although various kinds of solid fuel have been used for iron smelting, such as non-caking bituminous coal, anthracite, and charcoal, COKE is most largely employed at present. It is essential that the coking coal which is utilised is low in ash and has a sulphur content less than one per cent.

FLUX

The amount of flux used depends on the fusibility and composition of the slag to be obtained. LIMESTONE is invariably employed as flux in iron smelting. Its silica content should be less than 2 per cent.

CHARGE

The total sulphur content of the charge should not exceed 0.8 per cent. The charge consists roughly of 48 to 50 cwt. of ore, 12 to 9 cwt. flux, 25 to 30 cwt. coke, and 100 to 75 cwt. of hot air per ton of pig iron produced. The waste products consist of 30 to 10 cwt. of slag and 120 to 100 cwt. of flue gases. These figures of course depend on the quality of the ore.

HOT AIR

BLAST FURNACE

The chief reducing agent in the blast furnace is CO, carbon monoxide. The reduction of the ferric oxide to metallic iron may be represented by the generalised chemical equation $Fe_2O_3 + 3CO = Fe_2 + 3CO_2$. The limestone $CaCO_3$ breaks down into lime, CaO , and CO_2 , and the interactions with silica, SiO_2 , and alumina, Al_2O_3 , result in the formation of slag, $2SiO_2 \cdot Al_2O_3 \cdot 3CaO$, thus the products obtained are

HOT WASTE GASES

MOLTEN METAL

MOLTEN SLAG

which may be taken directly to the Bessemer Converters or Open Hearth Furnaces for conversion to STEEL or the melt is run into moulds to give

PIG IRON

This may be placed in suitable ANNEALING OVENS to produce MALLEABLE CAST IRON or it may be melted in a PUDDLING FURNACE for conversion to

WROUGHT IRON which is often treated by the CEMENTATION PROCESS for the production of BLISTER STEEL

Pig iron remelted in a CUPOLA FURNACE can be poured into moulds to obtain CAST IRON CASTINGS or the melt may be transferred to

OPEN HEARTH STEEL FURNACES (Regenerative gas fired types. Scrap iron and iron ore are always added to the melt).

or

BESSEMER CONVERTORS (Air blown. Heat maintained by the rapid oxidation of manganese, silicon, carbon, and phosphorous in charge.)

BASIC PROCESS Furnace bed lined with 'dead burnt' Dolomite. Limestone and Fluorspar added as flux.

ACID PROCESS Furnace bed lined with Gannister or Siliceous Sand. Ferro-manganese added.

ACID PROCESS Lining of Gannister bonded with clay. Spiegeleisen added.

BASIC PROCESS Lining of 'dead burnt' Dolomite with Tar as binder. Limestone for flux. Lastly spiegeleisen added.

BASIC (Phosphoric) SLAG

ACID SLAG

BASIC (Phosphoric) SLAG

STEEL

STEEL

FERRO-ALLOYS of Chromium, Manganese, Tungsten, etc., are added to the Molten Metal to give the several

SPECIAL TYPES OF STEEL which are available.



Plate III
Map showing the mineral resources of the Indian Empire.

that in the quadrangle, 400 miles east and west by 200 miles from north to south, with Calcutta at the northeast corner, there are 20,000 million tons of high-grade ore at an average distance of 125 miles from the Bengal coal-fields.

India's resources of good-quality iron ore are not limited to the iron belt. There are attractive occurrences of magnetite, hematite, clay ironstone, and especially of laterite ores, elsewhere in the country. It is true these ores are, in one way or another, not as attractive as those in the iron belt, nor in most cases are they so well located with regard to supplies of coking coal. But they are no further distant from the coal-fields of Bengal than are the Mesabi ores from the coal-fields of Ohio and Pennsylvania. Transportation facilities and a great domestic demand for iron, are, however, at present lacking in India.

The several Indian occurrences of iron ore are discussed below in detail.

Magnetite Ores

The largest known deposits of magnetite in India occur in the Madras Presidency, in the districts of Salem, Nellore, Nilgiri, and Padukotai. In the Salem district the reserves are estimated in thousands of millions of tons, but investigation has shown that ore averaging 55 per cent iron is not as common as was previously supposed. An average figure of about 39 per cent iron is thought to be a good all-round estimate. Further, as the ore is a quartz-magnetite rock, some process of concentration will have to be adopted, possibly magnetic separation. This will increase the cost of the ore while improving its grade. There is no doubt that quantities of high-grade ore occur in some localities. The principal occurrences of the Salem district are:

1. Godamalai, where two parallel bands are said to have been traced for a distance of 35 miles. The main bed is reported to have an average thickness of between 50 to 100 feet, and forms precipices several hundred feet high. The ore is often found interlaminated with quartz.

2. Thalaimalai-Kolimalai, where two series of beds are traceable for considerable distances and are well exposed on the Nalnamalai spur and above Pailam.
3. Singapatti-Singapuram, where three chief bands of ore are exposed on either side of a great synclinal fold — particularly on the northern side. The axis of the fold trends from west to east-northeast.
4. Thirtamalai, where two great beds form the crest of the hill range of the same name and continue northwards to the Ponnai river.
5. Kanjamalai, the ores of which area are thought to be the most valuable. Five bands of ore have been discovered. The two lowest are 50 to 100 feet thick and form conspicuous features in the scenery of the hill. The quantity of iron ore in this area alone would be considered almost inexhaustible. It must be very large. There is an admixture of hematite. Assays are reputed to have given the following results: iron, 55.07 per cent; sulphur, 0.028 per cent; phosphoric acid, 0.3 to 0.6 per cent. The Imperial Institute smelted some of this ore experimentally with Indian coke ⁽¹⁾ and obtained a yield of only 39 per cent metallic iron ⁽²⁾. They pronounced this ore as being unsuitable for use in modern blast furnaces. It is to be remembered that in 1853 the ill-fated East Indian Iron Co. erected a blast furnace, using charcoal, at Palampatti, on the Cauvery river, and is said to have obtained a yield of 60 per cent metal.

The great drawback to working these magnetite ores of Salem on a large scale is the scarcity of cheap suitable fuel. Calculations have been made by Sir Thomas Holland to show that, with the greatest efficiency in the management of the reserved forests of Salem, there would scarcely be enough charcoal for the annual production of 1,500 tons of pig iron. The question of transporting these Madras ores to the Bengal

⁽¹⁾ Made from Sanctoria coal. This seam occurs almost at the base of the upper or Raniganj stage of the Damuda series in the Raniganj coal-field. See remarks on coking coals.

⁽²⁾ Samples taken from outcrop exposures by officers of the Geological Survey of India gave from 37 to 39 per cent iron.

coal-fields does not arise at present, and unless some special process of iron smelting is devised it may be very many years before they are likely to be used for the production of iron and steel.

Lateritic Ores

True lateritic ores are, normally, partially dehydrated limonite, and contain appreciable percentages of alumina, titania, and other impurities in small amounts; but they are usually more or less free of silica. This refers to *primary*, or *in situ*, laterite. *Secondary*, or *detrital*, laterite is more complex and may contain enough free silica to be decidedly siliceous. Phosphorus and sulphur are present in varying amounts in both classes, while manganese may sometimes occur in appreciable percentages.

It is difficult to give an adequate idea of the vast spreads of laterite (low-grade lateritic ores, frequently averaging upwards of 30 per cent iron) which occur in the Indian Peninsula. Both classes of this kind of ore occur in association with the great flows of basaltic lava, known as the 'Deccan trap', which covers an area of 200,000 square miles in India. The primary laterite, usually from 5 to 50 feet thick, generally covers the tops of the trappean plateaux and water-sheds. The secondary laterite is usually found in the great tracts to the east and south and north which fringe the area occupied by the Deccan trap. Rich or highly ferruginous laterite does not occur everywhere, but large, although widely separated, spreads are known to exist in the region which extends from the Rajmahal hills in Bengal to the Bombay coast about Ratangiri, and from the Central Indian highlands of Gwalior to the Carnatic plains of Madras.

Much of the ore used in the agaria furnaces of the old industry of Birbhum (Bengal) was obtained from the laterite occurrences in the vicinity of Mallarpur. The average yield of this material (from 29 samples) was 43 per cent iron, with a phosphorus content (from 4 samples) of 1.5 per cent phosphoric acid. Rich deposits of ferruginous laterite occur in various parts of the Jabalpur district in the Central Provinces. It has been estimated ⁽¹⁾ that 49 million tons of this class of

(1) By Mr. F. R. Mallet. See *Rec. Geol. Surv. India*, Vol. XVI, p. 110.

ore, carrying 57.52 per cent iron with 0.76 per cent phosphorus, are available in the Kanhwara hills of this district. The lateritic ores of another occurrence — Agaria — in the same area, which also are suitable for blast furnaces, gave the following assay results: iron, 53.37 per cent; phosphorus, 0.146 per cent; sulphur, 0.02 per cent; and silica, 9.78 per cent. The Dungri (Rajpipla) ore is said to average over 52 per cent iron, and contains roughly 10 per cent silica and 9 per cent alumina. Most of the ore used in the almost forgotten iron-making centres of the agaria industry in the Bombay Presidency — Kathiawar, Rajpipla, Ratnagiri, and elsewhere — was rich lateritic ore.

As a guess, it would be near the truth to say that the average composition of normal primary laterite in India is 42.75 per cent ferric oxide (30 per cent iron), 37.70 per cent alumina, 20 per cent combined water and moisture, and 4.55 per cent of silica, titania, manganese, lime, magnesia, etc. Such an iron ore is not attractive to an iron smelter working with modern blast furnaces. However, I venture to predict that the large percentage of alumina may yet prove to be an attractive feature. I see no reasons of a theoretical nature against the smelting of such an ore with a limestone flux in a normal, though perhaps modified, blast furnace. It is conceivable that the working operations could be adjusted to produce a calcium aluminate slag which would be identical with the material known as bauxite cement or *ciment fondu* ⁽¹⁾. Perhaps the manufacture of this very valuable cement would be the primary object of the process and the pig iron a mere by-product of the operations. Taken either way, the results would give two saleable products, each, I think, at a cost below that at which these materials are now prepared, provided that the fuel and flux are obtainable at a reasonable price. Should such a process be embarked upon, I have no hesitation in saying that there is enough laterite in India to supply the existing iron and steel industry of the world with pig iron for many years to come, and at the same time to produce enough cement to meet the world's demand for this commodity.

⁽¹⁾ *Mem. Geol. Surv. India*, Vol. XLIX, pt. 1, 1923; also 'Bauxite', by Cyril S. Fox; Crosby Lockwood, 1927.

Clay Ironstone

This type of ore invariably occurs in strata associated with the chief coal-bearing formations of India—in the Tertiary coal-fields of Assam, as well as in the Gondwana coal-measures of the Damuda valley. Such ironstones, of the class known as 'black-band' (or carbonaceous) ore, have been largely used in the indigenous iron industry of Assam—about Tirugaon, Golaghat, and Jaipur. These ores seldom contain more than 40 per cent iron. Perhaps the best known occurrence is that of the Ironstone Shale stage between the Raniganj (upper) and Barakar (lower) Coal-Measure stages of the Damuda group of beds in the Raniganj coal-field. These carbonaceous shales contain bands of siderite which on superficial oxidation produce limonitic layers and nodules ⁽¹⁾. These on further weathering give rise to the hematitic ores (frequently only partially dehydrated limonite) which are such a marked surface feature of the Ironstone Shale stage wherever it occurs. It is quite true, as Dr. L. L. Fermor has said ⁽²⁾, that the superficial ironstone nodules form a much larger proportion of the shale of the surface exposures than does the un-oxidised carbonate ore of the shale in depth. This is very important in estimating reserves of ironstone ore. All the hematitic, or non-carbonate, ore in the Ironstone Shales is purely superficial, so that estimates of the reserves of this class of ore must be based on purely shallow depths of a few feet—10 feet, or perhaps 15 feet, only. In depth the nature of the ore will change entirely, and calculations must also take cognisance of the fact that thickness of ore to shale is less than one would be led to believe from surface exposures. Previous estimates of tonnage of these ores in the Raniganj coal-field are therefore quite useless. The statements quoted by me in my paper before the Mining and Geological Institute of India ⁽³⁾, to the effect that one foot of ore occurs in every 10 to 12 feet of shale, and that, with a thickness of 1,400 feet

⁽¹⁾ Based on observations during the present re-survey on the Raniganj coal-field. Of the 40 per cent iron, perhaps 30 per cent occurs as carbonate the remainder as peroxide; and there may be 10 per cent of lime in the analysis.

⁽²⁾ *Trans. Min. Geol. Inst.*, Vol. XX, Pt. 4, 1926, p. 363.

⁽³⁾ *Trans. Min. Geol. Inst.*, Vol. XX, Pt. 2, 1925, p. 108.

of shales traced disconnectedly for 33 miles, there are 200 million tons of ore per square mile, requires to be read with a new significance.

The workable area of the ironstone shales is probably not more than about 50 square miles, so that for the oxidized ore having a thickness of perhaps one foot the quantity per square mile becomes of the order of only 5 to 6 million tons, or a total in the Raniganj coal-field of 300 million tons scattered over an area of 50 square miles. With the underlying carbonate ores the estimate will be different, and from the point of view of quantity per square mile a little more attractive. There is, however, the question of change of blast furnace practice, and the handling of the 'cover' or overburden, to be considered after the oxidised ore has been utilized. Various analyses of the superficial ironstones show that this ore averages 38.92 per cent iron, 2.09 per cent phosphoric acid, and traces of sulphur. The ore used at Kulti ⁽¹⁾, during 1889 to 1906, is said to have contained up to 46 per cent iron — the oft-quoted analysis being: 65 to 66 per cent ferric oxide, over 2.5 per cent manganese oxide, up to 2 per cent lime and magnesia, from 5 to 9 per cent alumina, 10 to 13 per cent silica, 10 to 12 per cent combined water, 0.09 to 0.44 per cent phosphorus, with traces of sulphur. In 1906, the Kulti charges were first mixed with pure magnetite from the magnesian schist deposit of Turamdih, south of Tatanagar ⁽²⁾. Since 1914, the employment of ironstone in the Kulti furnace charges has been discontinued. The iron ore for these smelters now comes entirely from near Manaharpur ⁽³⁾, in Kolhan ⁽⁴⁾.

The agarias of the Giridih, Ramgarh, Bokaro, Karanpura, and neighbouring coal-fields still utilize the local ironstone when they laboriously make iron for market days or with which to appease their creditors. Attractive occurrences of ironstone, said to average 44.8 per cent iron, have been located in the Aurunga coal-field at Rajbar and Balunagar, and were considered in a scheme for erecting iron works at Balunath. Lime-

⁽¹⁾ Bengal Iron Co. Ltd., originally the Barakar Iron and Steel Co.

⁽²⁾ Previously known as Kalimati, a station on the main Bengal Nagpur railway, from which a branch line of three miles goes to Jamshedpur (old Sakchi).

⁽³⁾ On the Bengal Nagpur railway.

⁽⁴⁾ An estate in the Singhbhum district.

stone (marble) also occurs in that vicinity, but so far no coal of caking quality suitable for metallurgical use has been discovered in that field. Similar iron ores occur abundantly near Kodoloi, in the Raigarh-Hingir coal-field in the Central Provinces.

Hematite Ores

From the remarks previously made, it will have become clear that, in spite of her valuable resources of other ores, it is with the hematite ores that the Indian iron and steel industry is chiefly concerned at present. Both in quality and quantity, these ores, particularly those of the 'Iron Belt' of Singhbhum, are said to exceed any other known occurrence of the kind. In fact the oolitic iron ores of Lorraine, once negligently termed 'minette', and over which there has been so much Franco-German animosity since the discovery of the basic steel process, would be as lightly regarded as the ironstone ores of the Raniganj field did they also occur in the middle of the Damuda Valley region.

The hematite ores of the Iron Belt are by far the most important iron-ore deposits known in India today. They occur in a wide tract of, until recently, little known country — in Mayurbhanj State, in the States of Keonjhar and Bonai, and in the Kolhan sub-division of the Singhbhum district. Mr. C. P. Perin, working on behalf of the Tata Iron and Steel Co., goes so far as to say that in the quadrangle, 400 miles east and west by 200 miles from north to south, with Calcutta at the northeast corner, there are 20,000 million tons of high-grade ore at an average distance of 125 miles from the Bengal coal-fields. Mr. H. C. Jones gives the following estimates of the quantity of hematite, with not less than 60 per cent iron content:

Singhbhum district (chiefly Kolhan)	1,074	million tons
Keonjhar State.....	806	" "
Bonai State.....	656	" "
Bonai or Keonjhar (disputed).....	280	" "
Mayurbhanj State.....	16	" "
Total.....	2,832	" "

Mr. Jones did not actually estimate the Mayurbhanj ores, but evidently refers to calculations made by the Tata Iron and Steel Co., wherein they consider the three areas of Gorumahisani ⁽¹⁾, Sulaipat, and Badampahar contain 16.5 million tons of high-grade ore ⁽²⁾. Very little of the Gorumahisani ore appears to be *in situ*; the bulk of it is scree or 'float' ore. One or two of the 'roots' of the original massive bodies, however, appear to remain, but no boring has been done to prove this. A little apprehension has been felt by some engineers and geologists regarding the continuation in depth of the other occurrences in the Iron Belt. In several cases, it has been found that the steely, massive ore passes down into softer material, which is often limonitic and strongly suggestive of the ore-bodies being of a merely superficial nature. Mr. Jones says his estimates have been made solely from surface observations, and that he has taken cognisance of the fact that, in ores of this kind, it is impossible to say, without testing, what happens below ground ⁽³⁾. In the case of solid *in situ* ore, 10 cubic feet, as a minimum, are reckoned per ton of ore, although theoretically 7 cubic feet of solid hematite go to the ton. With porous ores of a shaley nature, 12 to 15 cubic feet have been taken to the ton. In the case of *débris* occurrences, a maximum thickness of 5 feet has been considered, and 30 to 50 cubic feet of ground, depending on the nature of the occurrence, are computed to one ton of ore. There are also immense quantities of lower grades of ore in the tracts named.

The following analyses will give some idea of the excellent quality of the ore available from the various deposits in the Iron Belt:

(1) Also spelt Gurumaishini and Gurumaisini.

(2) There are also some 16 million tons of titaniferous magnetite in rather rich deposits which have not been taken up, as the ore contains upwards of 1 per cent of titanium.

(3) It is impossible, owing to the steepness of the slopes in many places, to make a fixed allowance for thickness. A geologist can, if he has good exposures, make a shrewd estimate of superficial quantities, and I do not remember hearing Mr. Jones complain of lack of exposures. It may be taken that his estimates are conservative.

Analyses of Indian Hematite Ores

	1	2	3	4	5	6	7
Metallic iron.....	59.78	66.78	59.60	61.20	64.00	66.35	69.21
Phosphorus.....	0.078	0.044	0.054	0.066	0.05	0.058	0.005
Manganese.....	0.61	0.192	0.24	nil	0.04	0.151	...
Sulphur.....	?	...	...	...	0.002	0.108	0.012
Silica.....	5.16	1.49	4.58	3.06	2.10	1.44	0.82
Alumina.....			4.62	3.04	1.25		
Lime.....			0.32	0.25	0.15		
Magnesia.....			0.10	trace	0.18		

1. Mayurbhanj (Gorumahisani) ore. Average of 5 years output for the Tata Iron & Steel Co., Ltd. *Rec. Geol. Surv. India*, Vol. LVII, 1925, p. 144.

2. Mayurbhanj (Sulaipat) ore. Average ore for 1923 for the Tata Iron & Steel Co., Ltd. (*op. cit.*, p. 146).

3. Keonjhar (Jhillingburu, Gua) ore as used by the Indian Iron & Steel Co., Ltd. (Information kindly supplied).

4. Keonjhar (Bonomali buru, Gua) ore as used by the Indian Iron & Steel Co., Ltd. (Information kindly supplied).

5. Singhbhum (Pansira buru, Kolhan) ore. Average analysis of ore used by the Bengal Iron Co., Ltd. (*op. cit.*, p. 136.)

6. Drug (Rajhara) ore. Average of 64 samples (*op. cit.*, p. 154.)

7. Chanda (Lohara) ore. The Pipalgaon ore is said to be somewhat better.

Note.—Keonjhar ore from Barabil area, with 65 per cent iron and 0.05 to 0.025 per cent phosphorus, was being supplied to the Government Shell Factory at Ishapur.

Analyses of the Ironstone Shales ore

(As used in the smelters of the Barakar ironworks previously)

	Areas west of the Barakar river			Area Kulti to about Ethora			Area about Churulia, from Jamagar to Toposi		
	max.	min.	av.	max.	min.	av.	max.	min.	av.
Iron.....	47.70	39.00	45.25	43.40	41.30	42.41	43.50	41.80	42.91
Silica.....	21.80	18.40	19.90	19.40	16.70	17.56	17.40	16.00	16.70
Phosphorus.....	1.37	0.23	0.44	0.86	0.79	0.82	1.15	0.64	0.90
Manganese.....	1.60	0.57	0.93	1.90	1.61	1.78	3.62	2.56	2.85
Moisture.....	2.20	1.00	1.68	2.90	1.00	1.80	5.10	1.30	2.84

Supplied to H. Walker by the Bengal Iron & Steel Co., Ltd., Kulti (*Trans. Min. Geol. Inst. (India)*, Vol. VII, 1913, p. 276.

Apart from their remarkably high iron content, these hematites are characteristically low in sulphur — the amount is seldom more than a trace and never appears to exceed 0.6 per cent. Titanium is an exceedingly rare constituent. The insoluble matter, which is largely silica, varies from 0.05 per cent in the massive ores to about 11 per cent in the more porous types. The phosphorus content varies greatly, but is thought to average 0.08 per cent, although it is known to exceed 0.1 per cent in some places. Manganese constitutes another variable component. It rarely exceeds 1 per cent in the steely massive ores, but may be present in larger amounts in the porous ores. In some types, a gradual passage is traceable from an iron ore low in manganese to a ferruginous manganese ore containing equal amounts of iron and manganese. Magnetite is not commonly present in these hematite ores.

In Burma, hematitic ores have been reported as occurring in several places in the Amherst district, in the Shan States and near Mandalay. There is an abundance of excellent limestone (marble and dolomite) at no great distance from the iron-ore deposits, but the supplies of iron ore are said to be strictly limited, while the question of fuel is already acute in Burma for locomotive and other purposes. At the present time, iron ore is being used as a flux in the lead smelting operations at Bawdwin, and even the deposits of ore for this purpose have not proved as large as was anticipated. The lead ores in the newly re-discovered extensive Chinese workings, near He Ho, south of Mandalay will, if they are worked, require considerable quantities of iron ore as flux. Until really attractive deposits of iron ore are found, and the coal question is satisfactorily answered, from local discoveries or cheap importations of coke, the subject of establishing a serious iron industry in Burma must remain merely a topic for conversation. It can safely be said that it will be some time before a project for erecting a large ironworks assumes practical proportions.

In the Central Provinces in the Peninsula, hematite ores have been located in the Chanda and Drug districts. The Chanda occurrences have been known for some time. The deposit of Lohara hill has been traced, according to report,

for a distance of over $2\frac{1}{2}$ miles. The hill itself is 600 yards long by 200 yards wide and about 120 feet high. It is reputed to contain at least 10 million tons of good-quality hematite. Average Lohara ore is said to contain 61.2 to 67.76 per cent iron, 1.5 to 11.04 per cent silica, 0.012 per cent sulphur, and 0.005 per cent phosphorus.

An unsuccessful attempt was made to smelt the Lohara ore at Warora in 1875. It is thought that charcoal was used as fuel, because the coals of Warora and other places in the Wardha valley are of a non-coking variety. Another project, which, however, never materialized, was to work the hematite of Pipalgaon with that of Lohara and employ charcoal fuel and an excellent local limestone. The proposal was to erect the smelters at Durgapur, on the Irai river near Chanda. In view of the probability of a change in smelting practice and the introduction of electrical methods of reduction, there is always the possibility that, with cheap coal, good local limestone, a high-grade iron ore relatively low in phosphorus, and the existence of manganese ore in the adjacent district of Nagpur, the manufacture of ferro-manganese might prove profitable.

In the Drug district, the most valuable deposit of hematite is that of Rajharra, in the Dondi-lohara Zemindari. This tract, together with the excellent limestone occurrence at Dalli, has been secured by the Tata Iron and Steel Co. as reserve for their furnaces at Jamshedpur ⁽¹⁾. The ore averages 66.33 per cent iron, 0.058 per cent phosphorus, 0.108 per cent sulphur, 1.44 per cent silica, and 0.151 per cent manganese. The proved reserves at Rajharra hill alone are said to be of the order of 6 to 10 million tons. The fuel question would probably prove a difficulty if local iron-works were contemplated. A local coal of caking quality has recently been discovered in the Korba coal-field in the neighbouring district of Bilaspur, but large-scale tests have not yet been carried out and it may only prove a valuable gas-making coal. In the circumstances, charcoal would be the only local fuel, and as Dr. Fermor has said ⁽²⁾, "A simple calculation shows that an attempt to run

⁽¹⁾ This company obtains some of its present supplies from Noamundi, in the Singhbhum district. This is additional to the Mayurbhanj source of supply. They do not work at Rajharra at present.

⁽²⁾ Indian Munitions Board Handbook, p. 129.

on charcoal a modern blast furnace producing pig iron would require the allotment of an area of forest — allowing for felling in rotation and replanting — altogether out of all proportion to the results obtained". The subject of electric smelting might receive support from the fact that attractive hydro-electric sites exist on the Nawagarh highlands in the adjoining district of Raipur.

There are many important iron-ore deposits in Mysore State — chiefly hematite mixed with magnetite. Of these, the most valuable appear to be those of the Bababudan hills. In this area there are said to be upwards of 30 million tons of ore carrying 60 per cent iron. It is interesting to know that these deposits, in spite of the entire absence of any coal-field in the State, are being exploited by the Mysore Wood Distillation and Iron Co. (the Bhadravati ironworks of Benkipur), under the managing agency of Messrs. Tata & Sons. Their pig iron, of good quality, has already found a sale in Europe, although recent conditions in England had seriously affected the profits and the company has had other difficulties. The question of supplementing the wood fuel by means of electric energy has not been forgotten, and it is hoped that, with better sales for the 20,000 tons of charcoal pig-iron annually produced, and a market for wood alcohol and grey acetate of lime, the time will come when extensions may be carried out. The State has important deposits of manganese ore which may also prove valuable for the preparation of ferro-manganese of American specifications.

Failure has been written in large letters across all efforts to work the hematite ores of Kumaon, in the United Provinces. The ores concerned are the talcose-slate hematites of Ramgarh (42.93 to 61.33 per cent iron), and the specular (scaly) hematite of Dechauri (38.82 to 55.13 per cent iron). An attempt was made in 1862, and a final effort during the period 1877-79, to establish iron works in the Kumaon Himalaya, near Naini Tal. Furnaces were erected at two places and operated by the North Indian Kumaon Ironworks, Ltd. The two classes of ore were mixed together. After considerable support from Government, the operations were reluctantly discontinued. The failure in this instance is ascribed to a combination of

causes — incompetent management, lack of suitable fuel in sufficient quantities, and the high cost of transporting the siliceous Ramgarh ore to mix with the aluminous Dechauri material.

Duration of Supplies

On an earlier page it was stated somewhat optimistically that the requirements of the Indian iron and steel industry in 1928 might be computed at 2,650,000 tons of hematite ore; it has also been estimated that there are of the order of 3,000 million tons of this material of high-grade in the Iron Belt of Bihar and Orissa — so that there is, on this basis, a supply for one thousand years. If we consider the projected requirements of the several companies who have acquired leases in the Iron Belt, *viz.*, an amount equal to roughly 10 million tons annually and capable of producing 6 to 7 million tons of pig iron (*i.e.*, approximating to the pig-iron production of Great Britain in normal times), then these reserves will be sufficient for 300 years. We can, therefore, for all practical purposes, consider the hematite ores of Bihar and Orissa as inexhaustible. The needs of smelters elsewhere, *e.g.*, in Mysore, Madras, and the Central Provinces, are also amply provided for from local deposits for an equally long period.

These remarks are perhaps not quite definite enough with regard to the nature of the ores, which must influence, especially by their sulphur and phosphorus content, the brand of pig iron produced. The details given previously have shown that no fear need be anticipated on the score of the sulphur percentage. It is when we come to the subject of phosphorus that difficulties begin. The prevailing opinion in India and elsewhere has been that it is the Gondwana coals which are to blame, by their relatively high phosphorus content, for the inability of Indian iron-masters to produce pig iron of Bessemer quality. Professor T. Turner ⁽¹⁾ has made the statement that "If it is desired, with an ore containing 50 per cent metallic iron, to produce pig iron containing under 0.06 per cent of phosphorus, the ore must not contain over 0.02 per cent of phosphorus unless the coke contains less than this small proportion."

(1) The Metallurgy of Iron, 1909, p. 199.

When we remember, even bearing in mind the superior iron-content of the Indian hematite ores, that the material from Gorumahisani and Sulaipat (of Mayurbhanj) carries, respectively, 0.078 and 0.044 per cent of phosphorus, and that ore from Pansira Buru (Kolhan) averages 0.05 per cent, it is evident that it is with their iron ores that the Indian metallurgists are first handicapped in this respect. From the analyses to hand it would appear that Lohara hematite (Chanda district, C.P.), with 0.005 per cent phosphorus, represents material with attractive features in this respect.

There is said to be 100 million tons of this ore, but whether or not it all has the same low phosphorus content I do not know. If, therefore, coke with sufficiently low phosphorus could be utilized with the Chanda (Lohara) hematite, there is enough material for making 70 million tons of pig iron of Bessemer quality. Assuming one million tons a year, there is enough for three generations. The question of making ferro-manganese of standard quality from manganese ore in the adjoining district of Nagpur also hinges on whether this material is sufficiently low in phosphorus. The answer to this will be seen when I come to consider the Indian reserves of manganese ore.

COKING COAL*

When we turn from the subject of iron ore to a consideration of the domestic reserves of coking coal we pass from an atmosphere of justifiable optimism to one of unnecessary pessimistic alarm. The first note of this despondency was struck in the report of the Coal-fields Committee of 1920, in which they say, not speaking particularly of coking coals, that

“It has been calculated that the Raniganj coal-field alone contains over twenty thousand million tons of coal of all kinds; most of this, however, is inferior, and only

*By the term coke is really meant the fixed carbon and incombustible impurities which remain after a coal has been subjected to destructive distillation (coking, either at high temperatures or by low-temperature carbonisation). If the product retains considerable amounts of volatile matter it is termed ‘soft coke’ (*poora koela* in India) or ‘smokeless fuel’.

The word ‘caking’ refers to the physical properties of the coke — to the hardness and compactness of the product. The designation ‘coking coal’ however, has come to be applied to a coal which, when subjected to coking, first softens and swells and then agglomerates into a hard compact coke.

518 million tons have been estimated to be of better, or so-called 'first class', quality. The addition of the Jharia reserves of higher grade coal would bring the estimates of the two fields up to nearly a thousand million tons, but this figure may need modification in view of the large quantities of coal now known to have been destroyed in both fields by intrusive igneous rocks. Further to the west, the Bokaro field is said to contain over six hundred million tons of coking coal, and it is possible that further reserves will be found in the Karanpura field. Apart from these, the only other coking coal known to occur in any quantity in India is that of Assam, the sulphur content of which, however, renders it unfit for metallurgical purposes. So far as we know, therefore, India will be dependent for her supplies of metallurgical coke on the group of fields lying in the Damuda valley and including Raniganj and Jharia; and, although the total amount of coal that they contain is undoubtedly very large, the quantity available for coke manufacture is strictly limited."

In the discussion on my paper, Mr. R. G. M. Bathgate ⁽¹⁾, in words full of meaning, says that the compiled estimates as submitted by me were "based on premises entirely faulty.... estimates he fully admits are of the nature of guesses....". He continues:

"My own rough figures of the good coking coals of Jharia, allowing for the known natural-coked areas.... give 1,100 million tons as the gross original virgin coking coal of the field. From available records it would appear that roughly 180 millions of tons of coal to date have been despatched from this field. Assuming three-fourths of this total to be first-class coal, we have 135 millions of tons of good quality coal despatched. This figure of 135 millions of tons, however, is far from being the total amount of coal exploited to yield these despatches. Mr. Treharne Rees did not overstate the case when he put working loss at $33\frac{1}{3}$ per cent, but to this latter figure must be added others bringing up a still more formidable total. Boiler consumption amounts (in 1923) to 15 per

(1) *Trans. Min. Geol. Inst., Ind.*, Vol. XX, pt. 4, 1926, pp. 348-358.

cent on the despatch figure, or using Treharne Rees' figure for working losses, 10 per cent on the gross coal. Coal for labour, theft, etc., will easily account for a further 7 per cent on despatch figures or say 5 per cent on gross. Collecting these percentages we get $33\frac{1}{3}$ plus 10 plus 5 = $48\frac{1}{3}$ per cent. But this is not all. Fires, collapses, coal locked up under railway lands, coal in barriers, etc., represent very considerable quantities of coal lost, and I consider I am placing my estimate low by saying that 50 per cent of the coal exploited is lost in producing the coal available for despatch from the collieries.

"To despatch 135 millions of tons of coal, therefore, means that 270 millions of tons have been exploited, and the total of 1,100 millions of tons originally is now reduced to 830 millions of tons. This figure of 830 millions of tons gross of good-quality coking coal in the field will suffer all the losses calculated for the past, unless hydraulic stowing becomes the general vogue. The total amount available for despatch on present-day general practice is thus likely to be in the region of 50 per cent of 830 millions, *i.e.*, 415 millions of tons".

On these data, and not seriously considering the availability of good-quality coking coal in any other but the Jharia coal-field, except perhaps the subject of blending Dishergarh (Raniganj field) coal with some of the Jharia fuel, Mr. Bathgate calculates, on the present annual production of 8 million tons of good-quality coal and the basis of a 5 per cent increase on this amount yearly, that the Indian coking-coal reserves, of material suitable for metallurgical purposes, will be practically exhausted in 30 years. Concluding, he says: "If, however, I am out 25 per cent or even 50 per cent in my estimate, such error would not detract from the grave seriousness of the situation." It is to be remembered that this 8 million tons is not being used for metallurgical purposes now. The present consumption for this purpose is barely 2 million tons, and at a maximum was anticipated to be 4 million tons by 1928. Some of the coal used for coking purposes comes from the Giridih coal-field, where probably the best coal of this kind in India occurs. Most of the good-quality coking coal above

referred to is being used for locomotive and other steam-raising purposes ⁽¹⁾. However, these are matters of trade; all that concerns the subject of my paper is to show what coals of coking quality are *available* ⁽²⁾. In a paper read before the West of Scotland Iron and Steel Institute (in 1925), Mr. Edgar C. Evans is credited with saying that "The problem has yet to be solved of devising a suitable test which would give both the coke maker and the blast furnace manager an idea as to the behaviour of coke in the furnace". It seems logical to consider that a large margin of variability in the percentage composition of a coke is permissible, depending on the purity of the iron ore to be smelted and on the nature (composition) of the coke ash, provided always that the coke will not crush under the weight and abrasion to which it must be subject in the sliding of the charge in the furnace. From careful enquiries which I have made since my paper was read and discussed before the Mining and Geological Institute of India, I find that there is a considerable disagreement, in the reputed publicly expressed opinions of the iron-masters of Kulti, Hirapur, and Jamshedpur, as to what they are said to consider suitable coking coals of Indian origin. I find that these differences of opinion vanish with regard to those coals with which the metallurgists at these works have had personal acquaintance in practice. It is, therefore, with a wider knowledge of the separate details than is possessed by the several metallurgists individually that the following statements on Indian coking coals are now made. Excluding, for the purposes of the iron and steel industry, the valuable though sulphurous Tertiary

(1) This cannot be helped, unless the Government acquire the leases of all coal lands and portion out the several fields and seams for specific purposes. This will seriously interfere with the efficient mining of the coal, and a good coking-coal seam reserved for a limited output may be hopelessly spoilt by more energetic mining in a steam-coal seam immediately below it. "Each coal concern acquired its coal-land with a view of early exploitation and of sales in most profitable market available. Conservation is not so vital to its policy as financial success, and with a coal trade with established markets and commitments, it is not justifiable to ignore its economies."

(2) It has somehow become the opinion of Mr. Bathgate and others that the Giridih coal is not available to any buyer. This is not quite correct. The Bengal Iron Co., Ltd., and the Tata Iron and Steel Co., have used this coal and can buy it whenever they want. Domestic economy, however, has necessitated that they employ coals from their own collieries or of a cheaper nature when suitable.

coals of the Assam field, it may be broadly stated, so far as available information shows, that caking coals, which can be used, either directly or by blending, for metallurgical coke manufacture, occur in the Giridih, Jharia, Raniganj, and Bokaro coal-fields.

The Giridih Coal-field

There are three seams of coal in this field ⁽¹⁾ which have been exploited: the Bhaddoah, and the upper and lower Karharbari. It is the lower Karharbari that is of interest to us in this report. All the seams are thought to occur in the Barakar stage of the Damuda series, though the opinion has been expressed that they are older and constitute a sub-stage of the underlying Talchir stage. On stratigraphical grounds, however, it seems best to consider these coal measures as part of the Barakar stage, irrespective of whether the lower coal occurs in strata of an early Barakar epoch which are not found elsewhere in the fields of the Damuda valley. The lower Karharbari seam occupies an area of 7 square miles. It has an average thickness of, approximately, 15 feet. Throughout the State Railway collieries (Serampore and Karharbari), it is of good coking quality. Some years ago it was estimated ⁽²⁾ that this field contained 105 million tons of workable coal, but that, allowing for wastage in working and damage done by igneous intrusions, the quantity available then was about 80 million tons. Allowing for the extraction which has taken place since, it is computed that the available reserves of the lower Karharbari seam probably do not exceed 40 million tons. My investigations in this field, during a few days of 1926 at the State Railway collieries, showed that the coal in the two collieries (Serampore and Karharbari) varied in thickness and composition (See the accompanying analyses, Tables I to VI, which were very kindly made for me by Mr. A. Dawes Robinson, of the Bengal Iron Co., Ltd., at Kulti). From these figures and

⁽¹⁾ Known in earlier reports as the Karharbari coal-field.

⁽²⁾ T. W. Hughes, *Mem. Geol. Surv. India*, Vol. VII, part 4, p. 35.

TABLE I

Analyses of samples (A) from Deep pit, Serampore colliery, Giridih

	Roof coal, 4 feet	Top middle coal, 4 feet	Middle coal, 9 feet	Lower middle coal, 4 feet	Floor coal, 3 feet
Fixed carbon.....	61.06	58.33	61.61	55.48	44.66
Volatile matter.....	24.40	25.10	24.40	23.78	15.55
Moisture.....	1.40	1.50	1.20	1.60	1.80
Sulphur.....	0.40	0.39	0.39	0.34	0.39
Ash.....	12.74	14.68	12.40	18.80	37.60

Details of ash impurities, given as percentages in the coal:

Silica.....	9.019	9.689	6.572	10.908	...
Alumina.....	2.567	3.523	3.744	5.720	...
Ferric oxide.....	0.395	0.616	1.240	0.123	..
Manganese oxide.....	0.132	0.135	0.135	0.193	...
Lime.....	0.255	0.188	0.198	0.206	...
Magnesia.....	0.108	0.132	0.098	0.165	..
Sulphur trioxide.....	0.018	0.023	0.019	0.033	...
P ₂ O ₅	0.112	0.179	0.270	0.114	0.127
Alkalies.....	0.137	0.187	0.121	0.225	...

Note.—The sulphur trioxide in the ash re-calculated to the coal is misleading.

Phosphorus in coal.....	0.049	0.078	0.119	0.048	0.056
-------------------------	-------	-------	-------	-------	-------

All coking coals.

Average of (24 samples) full thickness of seam, 24 feet:

Ash.....	17.05	per cent
Phosphorus in coal.....	0.0987	" "

(Analyses by A. Dawes Robinson).

TABLE II

Analyses of samples (B) from North Central No. 2 pit,
Serampur colliery, Giridih.

	Roof coal	Upper middle coal		Middle coal				Lower mid- dle coal	Floor coal
	4 feet	1 foot	2 feet	1 foot	1 foot	1 foot	1 foot	5 feet	3 feet
Fixed carbon.....	57.31	53.43	58.93	54.75	63.43	57.17	61.87	53.35	43.35
Volatile matter.....	26.0	23.8	25.10	20.30	26.00	23.20	23.10	24.50	17.5
Moisture.....	1.40	1.40	1.45	1.60	1.40	1.40	1.30	1.40	1.20
Sulphur.....	0.39	0.37	0.37	0.35	0.37	0.33	0.33	0.35	0.35
Ash.....	14.90	21.00	14.15	23.00	8.80	17.90	13.40	20.40	37.60

Details of ash impurities, given as percentages in the coal:

Silica.....	10.281	...	9.706	...	5.033	12.53	7.396	...	...
Alumina.....	2.443	...	2.945	...	2.413	3.615	4.054	...	...
Ferric oxide.....	1.370	...	0.727	...	0.754	0.823	0.956	...	...
Manganese oxide...	0.147	...	0.128	...	0.092	0.194	0.132	...	...
Lime.....	0.283	...	0.240	...	0.202	0.322	0.321	...	...
Magnesia.....	0.156	...	0.152	...	0.104	0.182	0.163	...	...
Phosphoric acid....	0.034	0.037	0.037	0.033	0.103	0.671	0.175	0.203	0.065
Sulphur trioxide....	0.026	...	0.017	...	0.011	0.025	0.020	...	...
Alkalies, etc.....	0.156	...	0.179	...	0.083	0.134	0.178	...	...

Note.—The sulphur trioxide in the ash re-calculated to the coal is misleading.

Phosphorus in coal...	0.015	0.017	0.014	0.015	0.045	0.032	0.076	0.089	0.03
-----------------------	-------	-------	-------	-------	-------	-------	-------	-------	------

All coking coals.

Average of (19 samples) full thickness of seam, 19 feet:

Ash.....19.01 per cent
Phosphorus in coal..... 0.045 “

(Analyses by A. Dawes Robinson.)

TABLE III

Analyses of samples (C) from Jubilee pit,
Karharbari colliery, Giridih.

	Top of seam	Middle of seam	Bottom of seam
Fixed carbon.....	64.34	65.94	69.53
Volatile matter.....	26.50	25.50	23.50
Moisture.....	1.40	1.20	1.60
Sulphur.....	0.36	0.36	0.37
Ash.....	7.40	7.00	5.00

Details of ash impurities, given as percentages in the coal:

Silica.....	5.032	3.92	2.94
Alumina.....	1.740	1.84	1.26
Ferric oxide.....	0.232	0.84	0.520
Manganese oxide.....	0.068	0.071	0.051
Lime.....	0.133	0.084	0.060
Magnesia.....	0.077	0.110	0.082
P ₂ O ₅	0.013	0.015	0.0055
Sulphur trioxide.....	0.013	0.011	0.009
Alkalies.....	0.078	0.099	0.072

Note.—The sulphur trioxide in the ash re-calculated to the coal is misleading.

Phosphorus in coal.....	0.0059	0.007	0.0025
-------------------------	--------	-------	--------

All coking coals.

Average of samples for thickness 14 ft. 6 in. of seam:

Ash.....6.47 per cent
Phosphorus in coal.....0.0052 “

(Analyses by A. Dawes Robinson.)

TABLE IV

Analyses of samples (D) from Bitagarha pit,
Karharbari colliery, Giridih.

	Top of seam	Middle of seam	Bottom of seam
Fixed carbon.....	63.16	65.15	50.95
Volatile matter.....	23.00	28.10	19.80
Moisture.....	1.40	1.50	1.40
Sulphur.....	0.44	0.45	0.45
Ash.....	12.00	4.80	27.80

Details of ash impurities, given as percentages in the coal:

Silica.....	7.488	2.784	14.905
Alumina.....	3.432	1.334	8.463
Ferric oxide.....	0.480	0.475	2.650
Manganese oxide.....	0.111	0.044	0.202
Lime.....	0.072	0.067	0.328
Magnesia.....	0.129	0.037	0.353
P ₂ O ₅	0.013	0.015	0.013
Sulphur trioxide.....	0.019	0.008	0.049
Alkalies, etc.....	0.254	0.075	0.421

Note.—The sulphur trioxide in the ash re-calculated to the coal is misleading.

Phosphorus in coal.....	0.0057	0.007	0.0063
-------------------------	--------	-------	--------

Average of samples for full thickness, 18 feet, of seam:

Ash.....14.73 per cent
Phosphorus in coal..... 0.0063 “

(Analyses by A. Dawes Robinson.)

TABLE V

Analyses of samples (E) from Ramnadih pit,
Karharbari colliery, Giridih.

	Top of seam	Middle of seam	Bottom of seam
Fixed carbon.....	66.61	60.72	64.19
Volatile matter.....	21.10	24.80	25.20
Moisture.....	1.80	1.40	1.40
Sulphur.....	0.49	0.48	0.41
Ash.....	10.00	12.60	8.80

Details of ash impurities, given as percentages in the coal:

Silica.....	7.08	8.290	4.963
Alumina.....	1.840	3.094	2.544
Ferric oxide.....	0.60	0.647	0.728
Manganese oxide.....	0.093	0.117	0.130
Lime.....	0.140	0.126	0.140
Magnesia.....	0.108	0.181	0.139
P ₂ O ₅	0.022	0.027	0.019
Sulphur trioxide.....	0.008	0.020	0.012
Alkalies, etc.....	0.109	0.094	0.121

Note.—The sulphur trioxide in the ash re-calculated to the coal is misleading.

Phosphorus in coal.....	0.01	0.012	0.009
-------------------------	------	-------	-------

Average of samples for full thickness, 10 feet, of seam:

Ash.....10.47 per cent
Phosphorus..... 0.010 “

(Analyses by A. Dawes Robinson.)

TABLE VI
Averages of samples, Tables I to V

Pit	Ash	Phos- phorus in ash	Phos- phorus in coal	Depth to top of seam (feet)	Thick- ness of seam (feet)
Deep.....	17.05	0.579	0.0987	840	24
North Central No. 2...	19.01	0.238	0.045	340	19
Jubilee*.....	6.47	0.077	0.0052	772	14½
Bitagarha.....	14.73	0.072	0.0063	222	18
Ramnadih.....	10.47	0.100	0.0103	150	10

*In Jubilee pit there are two coal seams, the upper 5 ft. thick and the lower 9 ft. 6 in., separated by 3 ft. of stone.

a study of the plans, I estimated that in the Karharbari Colliery area alone there were of the order of 9 million tons of valuable coking coal averaging less than 10 per cent ash and with a phosphorus percentage not much more than 0.01. It is evident that in this fuel we have a coke-making material which is of a grade almost equal to the best obtainable in Europe or America (so far as its phosphorus content is considered). If suitable low-phosphorus iron ore and manganese ore were available, it is clear that we would then have the raw materials necessary for the production of pig iron of Bessemer quality or of ferro-manganese of standard grade.

It is to be regretted that nearly all the coal raised at the State collieries is used for locomotive purposes. The coke which is made from the coal slack is also entirely consumed for foundry and smithy purposes at the various railway workshops. It is difficult to see how work at these collieries is to be carried on otherwise. They cannot remain idle waiting for orders of coal or coke from the iron smelters of Jamshedpur, Kulti, and Hirapur. I believe I am correct in saying that definite orders for fixed amounts of this coal to keep the pits properly at work would be welcomed by Government, who would then obtain their railway fuel elsewhere.

The Jharia Coal-field

It is true that nearly all the coke for iron-ore smelting is obtained from the Jharia coal-field. Although the whole of the strata of the Damuda series is said to be present in this coal-field, it appears that seams of good coking coal are restricted to the lower, or Barakar, stage, and that these coking coals are present only in the middle to upper seams of this stage, *i.e.*, from No. 10 seam upwards to No. 18. Among these, the best coking coals appear to lie in seams No. 14, 14A, 15, and 17. In addition, there is a fairly good grade of coking coal in seams Nos. 11, 12, 16, and 18. Analyses of the coals of these seams are given in Tables VII to IX. (I am very grateful to Mr. C. S. Whitworth, Chief Mining Engineer, Railway Board, for analyses in Tables VII and VIII).

The Indian Iron and Steel Co. use coking coals from the following Jharia seams. (Information kindly supplied).

No. of seam	Colliery
13, 14 and 15.....	Gaslitan
12, 13, 14 and 15.....	Union
12, 13, 14 and 15.....	{ Sendra Standard Khas Jharia Bhulanbararee
11.....	National
11 and 12.....	Khas Angarpathra

The analysis of the coals (which are mixed together) is:

Fixed carbon.....	62.20 per cent
Volatile matter.....	25.74 “
Moisture.....	1.98 “
Ash.....	11.58 “
Sulphur.....	0.50 “
Phosphorus.....	0.10 “

TABLE VIII
Analyses of typical fairly good Jharia coking coals

	1	2	3	4	5	6	7	8	9	10	11	12
Fixed carbon.....	69.40	63.05	62.83	61.40	62.60	62.05	66.00	61.55	60.20	64.70	60.50	59.30
Volatile matter.....	14.00	18.75	23.57	20.50	20.70	22.45	20.10	23.90	24.50	25.20	28.05	28.80
Moisture.....	1.46	0.70	1.10	1.00	1.00	1.10	0.90	0.75	1.30	1.30	1.40	1.80
Ash.....	16.60	18.20	13.60	18.10	16.70	15.50	13.90	14.55	15.30	10.10	11.45	11.90
Calorific value (calories)...	7,299	6,882	7,576	7,142	6,874	7,245	7,200	7,211	7,240	7,572	7,437	7,209

1. No. 10	seam, Bastacolla	colliery (Balmer, Lawrie & Co.);	analyses by Alipur Test House.
2. "	" Kustore	" (Kilburn & Co.)	" " "
3. Nos. 10 and 11	seams, Bhowra	" (Mackinnon, Mackenzie & Co.)	" " "
4. No. 11	seam, Ekra Khas	" (Maharajah of Cossimbazar)	" " "
5. "	" Kusunda Nyadee	" (Martin & Co.)	" " "
6. No. 12	" Bhuggutdih	" (Andrew Yule & Co.)	" " "
7. "	" Central Kirkend	" (Anderson, Wright & Co.)	" " "
8. No. 13	" Kustore	" (Kilburn & Co.)	" " "
9. No. 16	" Bhagaband	" (F. W. Heilgers & Co.)	" " "
10. Nos. 16 and 17	seams, Pootkee	" (Mackinnon, Mackenzie & Co.)	" " "
11. No. 18	seam, Jamadoba	" (Tata Iron & Steel Co.)	" " "
12. "	" Noonudih-Jitpur	" (Bengal Iron Co.)	" " "

TABLE IX
Analyses of Indian coals and coal ash

	1	2	3	4	5	6		7
						Lower 24 ft. Upper 30 ft.		
Fixed carbon.....	58.33	64.68	56.75	55.20	53.64	52.81	51.33	51.25
Volatile matter.....	25.10	22.82	30.68	27.4	34.11	31.07	31.19	30.25
Moisture.....	1.50	1.5	...	2.0	2.25	1.36	1.91	2.50
Sulphur.....	0.39	{0.24 Fixed 0.52 Volatile	...	...	0.39	0.91	0.65	0.36
Ash details:								
Silica.....	9.689	4.914	5.99	8.285	5.050	8.66	8.56	7.760
Alumina.....	3.523	3.939	3.82	3.953	2.400	4.62	5.37	5.612
Ferric oxide.....	0.616	0.565	1.50	1.760	1.000	1.26	1.04	1.233
Manganese oxide.....	0.135	?	0.03	0.057	?	...	...	0.305
Lime.....	0.188	0.816	0.65	0.508	1.000	0.15	0.31	0.240
Magnesia.....	0.132	0.371	0.10	0.215	0.250	0.02	0.06	0.128
Sulphur trioxide.....	0.023 (ash)	?	0.07	?	?	0.02 (ash)	0.01 (ash)	?
Phosphorus pentoxide	0.179	0.185	0.17	0.252	0.314	0.12	0.21	0.083
Other constituents...	0.187	?	0.15	0.367	?	...	...	0.789
Ash — Total.....	14.68	11.00	12.57	15.40	10.00	14.76	15.35	16.00
Phosphorus in coal.....	0.075	0.077	0.068	0.105	0.13	0.05	0.09	0.035

1. Giridih, Serampur colliery, Lower Karharbari seam; probable fair average near Dip Pit. (A. Dawes Robinson).
2. Jharia, Bararee, machine-cut slack coal from lower part of No. 15 seam. (B. Wilson Haigh).
3. Jharia, Jamadoba, mixed sample upper (7 ft. 6 in.) and lower (5 ft.) No. 18 seam, and 7 ft. of No. 17 seam; 0.434 per cent TiO_2 . (F. G. Percival).
4. Raniganj, Ramnagar colliery, Ramnagar seam. This coal provided coke to the Bengal Iron Co. at Kulti. (A. Dawes Robinson).
5. Raniganj, Saltore colliery, Dishergarh seam. (Ash estimated from two analyses of Dishergarh seam.) (E. Spencer supplied P).
6. Karanpura, Upper Sirka Argada Thick seam (60 feet). This coal cokes very well with Saltore coal (Dishergarh seam). (E. Spencer).
7. Rammur, Ib River, Sambalpur District. Moisture variable and often large. Contains 0.761 per cent TiO_2 . (F. G. Percival).

while a complete analysis of the coke produced is:

Fixed carbon.....	76.45 per cent
Volatile matter.....	1.32 “
Moisture.....	2.58 “
Ash.....	19.37 “

Details of ash:

Silica.....	9.40 “
Alumina.....	5.59 “
Ferric oxide.....	2.44 “
Lime.....	0.89 “
Magnesia.....	0.12 “
Phosphoric acid.....	0.41 “
Sulphur.....	0.52 “

19.37 “

In my paper before the Mining and Geological Institute of India, I stated that the estimates of quantities of the coal available in the Jharia coal-field were exceedingly approximate



Figure 1.—Goodman 'shortwall' coal-cutting machine at Jamadoba colliery.

(Photograph by Bourne & Sheppard, Calcutta; kindly supplied by Messrs. Kilburn & Co. (Coal Dept.), Calcutta)

—little more than guesses. Since the discussion on that paper took place, I have been engaged on a re-survey of this field, but it will be several months before I can hope to make a definite statement as to the calculated reserves. Meanwhile Dr. David Penman ⁽¹⁾, Principal of the Indian School of Mines at Dhanbad, has made some enquiries and furnished the following information. He says:

“With regard to coal of good coking quality, I find that there is a total of over 600 million tons of coal available in 17, 15, 14A and 14 seams down to a depth of, say, 800 feet. If 13 seam is added, the total exceeds 800 millions; and if a portion of 12 seam and a portion of 18 seam (both of which yield good coking coal) are added, the total approximates to 1,000 million tons. This figure is not greatly in excess of Mr. Bathgate’s estimate of 830 million ⁽²⁾.

“My figures refer to areas which have been fully or partially proved. It is probable, I think, that further borings will show at least another 100 million tons of first-class coal at an economic depth.

“In addition, there are about 700 millions of tons of good second-class coal available in 18, 16, 12 and 11 seams to a depth say of 600 feet. Much of this coal would make a good coke, though somewhat high in ash, but would certainly give as good coke as the Kargali seam. There is also at least 500 millions of tons in No. 10 seam”.

Continuing, Dr. Penman says:

“There is one aspect, however, of the problem of the conservation of our reserves of first-class coking coal to which I should like to draw attention. At the present moment there are at least 125 million tons of coal standing in pillars in 17, 15, 14A, 14 and 13 seams. This represents about 8 to 10 years’ output of first-class coal standing in pillars. In addition, there is probably another 100 million tons in 18, 16, 12, 11, 10 and 9 seams. Some of those pillars are 20 to 30 feet high, and some are perhaps not so strong as they ought to be. It is well known that

⁽¹⁾ *Trans. Min. Geol. Inst. (India)*, Vol. XX, pt. 4, 1926, p. 395.

⁽²⁾ Quoted on an earlier page.



Figure 2.—Goodman 6-ton electric locomotive at Jamadoba colliery.
(Photograph by Bourne & Sheppard, Calcutta; kindly supplied by
Messrs. Kilburn & Co. (Coal Dept.), Calcutta)

practically all the fires which have occurred in the Jharia and Raniganj fields have occurred in depillaring areas. There is more coal on pillars at the moment than at any period in the history of the coal-field. In the taking out of pillars in these first-class seams, there is an ever-present risk of fire. Indeed, more than one prominent mining engineer has told me that he daren't run the risk of taking out pillars.

"Everyone agrees, of course, that the sure remedy for fire in thick seams is the hydraulic packing of the waste, but economic considerations in most cases, at present at any rate, rule out this remedy".

I think, in view of the doubtful nature of previous estimates of the Jharia coals — although it is to be remembered that Mr. R. R. Simpson estimated a total of 1,174 million tons of coking coal in this field — we must accept, for the present, the estimates compiled by Dr. Penman, which are limited to a

depth of 800 feet. Borings have shown that in several instances the coal has been coked by intrusions of igneous rocks, dykes and sills, in the deeper continuation of a seam. But it seems unreasonable to assume, in consequence, that all the seams are thus entirely destroyed in depth throughout the field. This is not borne out by experience, either in this coal-field or in that of Raniganj. Therefore, without too much optimism, it is probable that further reserves of good-quality coal will be proved within workable depths in a workable condition.



Figure 3.—General view of the coal-handling plant at Kustore. Note the 7-ton skip in dumping position. The skip is filled at the shaft bottom from a bin which is charged from tub tippers capable of holding three tubs at a time.

(Photograph by Bourne & Sheppard, Calcutta; kindly supplied by Messrs. Kilburn & Co. (Coal Dept.), Calcutta)

The subject of dispensing with a remedy ⁽¹⁾ which is steadily becoming a necessity rests, of course, with the firms in whose hands the coal lands lie. If Mr. Bathgate's allowance

⁽¹⁾ Hydraulic stowage. It may incidentally be mentioned that there are few coal-bearing regions so well served with a supply of sand as is the Jharia-field by the Damuda river.

for coal lost is right, and if non-coking or poorer coal can not be substituted for good-quality coking coal for steam raising ⁽¹⁾, it simply means that Dr. Penman's estimates of 1,100 million tons of good-quality, and 1,200 million tons of lower grade, coking coal must be halved, and that the remaining Jharia coal of 1,150 million tons available to the iron industry must get steadily worse and worse as regards the ash percentage as the better qualities become exhausted. It may mean, finally, the use of coal giving a hard coke, with 25 per cent of ash, but this is not really as bad as it looks, for the Tata Iron and Steel Co. were, until recently, using a coke containing an average of from 21 to 22 per cent ash, with 0.56 to 0.63 per cent sulphur, and 0.162 to 0.184 per cent of phosphorus. In my opinion it is *possible* to win, though perhaps impracticable to conserve, the whole of the good-quality coal for the manufacture of coke, and thereby obtain close on 700 million tons good-quality coke. The probability is that this reservation can never be carried out, owing chiefly to the more attractive prices given, and the quantities taken, by consumers other than the iron makers of Kulti, Jamshedpur, and Hirapur, and also to the severe competition which prevails in the coal industry. If prices could be fixed, perhaps a step in the direction of such conservation might be made. Nevertheless there are *available* supplies of potential Jharia coke which could last the 1928 projected requirements of the iron industry fully 200 years, while the possible expansion of the production of pig iron to 6 million tons a year, necessitating 9 million tons of coke, could be met for 70 years. There is certainly cause for some attention to detail — first, because hydraulic stowage has not become the vogue; second, that this coal is being used for purposes other than the manufacture of coke for metallurgical use; and third, because the deeper reserves have not been systematically proved by boring.

The Raniganj Coal-field

The information available from the Raniganj coal-field shows that coals of caking quality, moderately low in their ash content, occur in the western areas of the field in the

⁽¹⁾ At the State collieries at Giridih, the lump coal goes to railways, the slack is made into coke, and the fuel for steam raising is obtained from Kargali quarry in the Bokaro coal-field.

lower measures of the Raniganj stage and in the upper measures of the Barakar stage of the Damuda series. The seams particularly mentioned in the lower measures of the Raniganj stage are (a) the Dishergarh, (b) the Hathnal, and (c) the Sanctoria coals, southwest and south of Sitarampur. It is known that many acres of these seams have been destroyed by sills of intrusive trap ⁽¹⁾. Experiments on a practical scale carried out at Giridih, Loyabad, and Kulti are suggestive of the fact that only one or two of these coals will, taken by itself, produce a metallurgical coke strong enough to resist the crush and abrasion of the sliding charge in a blast furnace. However, any of them, if *carefully mixed* in the proportion of 50:50, occasionally 75:25, with good-quality Giridih or Jharia coking coal will yield a good coke. The most satisfactory for mixtures appears to be (a). It has also been found that (a) produces a fair-quality coke when mixed with the supposed non-coking coal of the Sirka-Argada seam from the Karanpura field.

My preliminary estimates of the reserves of the above three seams in the region west of Asansol and south of Sitarampur, and including the area about Saltore, down to a depth of 2,000 feet and assuming a thickness of 12 feet for (a), 6 feet for (b), and 8 feet for (c), are, in an area of 10 square miles ⁽²⁾, 120 million tons of (a), 60 million tons of (b), and 80 million tons of (c) — a total of 260 million tons. Of this, allowing 60 per cent for loss in mining, destruction by dykes and sills, and amount already won, the figures will become 48 million tons of Dishargarh coal, 24 million tons of Hathnal, and 36 million tons of Sanctoria. These could be rendered available for blending with coals from Giridih and Jharia, and partly with material from the Barakar stage of the same area (West Raniganj coal-field).

In his contribution to the discussion ⁽³⁾ on the subject of the coking quality of the Raniganj coals, Mr. R. Purdy says that he experimented with Dishergarh slack coal, "wet pressed, dry pressed, and then dry-loose, in the open type of

⁽¹⁾ Peridotites and mica peridotites, and, to a very much lesser extent, by dykes of dolerite — all about the same geological age.

⁽²⁾ Outcrop 5 miles, depth inwards 2 miles.

⁽³⁾ *Trans. Min. Geol. Inst. (India)*, Vol. XX, Pt. 4, 1926, p. 378.

oven". He then continued his experiments with "Lochipur seam, Hatgoorie seam, Kantipahari seam, and Begunia seam at Kantapahari. Bhuskajiri seam with difficulty made a coke, and Charanpur seams were more difficult still. East of Charanpur, I failed to get a seam to coke".

"As my general opinion, I would say that there is no metallurgical coke available in the Raniganj field except that made by mixing with the Jharia seams; the best coke of Raniganj is unable to carry a load, and others are heavy in ash".

These are statements by an experienced coke-oven manager, but although such a statement backed by experimental work is most valuable, it is necessary to remember that the coals experimented with largely came from the eastern-central Raniganj field. It may be admitted that work on similar seams — *e.g.* Ghusick, Nega, Borachuk, Baraboni, Kajora, Ragunathbatti, Choukidanga, Babisol, Jamehari, Madhabpore, Kenda, and Salanpur A, tested by Messrs. Lathbury and Marshall, from the same region — is in agreement with the above experiments by Mr. Purdy. However, the Laikdih-Victoria-Borrea coal, the Ramnagar seam, and the Begunia coals, were not then tested. These, however, belong to upper strata of the Barakar stage, which I propose to discuss.

Working tests on the upper-Barakar-stage seams of the Kulti and neighbouring tracts of the Raniganj field have shown that the following seams possess good caking characteristics: (d) the Begunia seam, (e) the Ramnagar seam, and (f) the mid-section of the thick Laikdih-Victoria-Borrea group of seams. Begunia, alone, gives a poor metallurgical coke on physical grounds; Ramnagar, alone, gives a satisfactory coke, equal to the lesser grades of Jharia; Victoria makes an excellent coke in every respect. Begunia and Victoria, mixed, give a fair-quality coke. Ramnagar and Dishergarh also make a very fair coke, particularly when used in the proportion 60:30. Unfortunately, the tonnage of these coals is not large, owing to the faults and intrusions which cut up the strata in which they occur; but it is possible to allow safely an area of about 3 square miles to each for a workable depth of 2,000 feet. If the thickness of each seam is taken as 6 feet, the amount of

coal from these three seams will together total roughly 149 million tons. Allowing a loss of 50 per cent through dykes, faults, and worked-out coal, there remains nearly 25 million tons in each seam as available for use — 25 million tons of the Victoria-Laikdih-Borrea for direct coke manufacture, or to give a slightly lower grade of coke when mixed with Begunia; and 25 million tons of Ramnagar to be mixed with Dishergarh coal or with Noonudih-Jitpur (Jharia Nos. 17 and 18 seams).

In regard to the subject of mixing either good coking coals with coking coals of poor (physical) quality, or with non-coking coals (as in the case of Karanpura-Sirka-Argada coal), I would, however, quote the remarks made by Messrs. G. C. Lathbury and G. W. Marshall ⁽¹⁾. They say, in a concluding statement:

“Unless the supplies of coking coals are seen for certain to be running very short, then we think that little is to be gained by adopting the policy of mixing, though it may come to this in the future.

“It would, we think, be a better policy to break up large coal (good coking quality) and use it for coke making instead of for other purposes.

“The coke obtained by mixing is certainly inferior, and to obtain it we sacrifice a large amount of really good coke. When the non-coking ⁽²⁾ coals have a high percentage of ash, then it is still more undesirable to resort to mixing as not only is the resultant coke of poor quality, but it has the disadvantage of being very high in ash in addition.

“When a non-coking coal of low-ash is mixed with a good coking coal, the resultant coke may not really be first-class, but it has the advantage of being cleaner.”

I append herewith analyses of these Raniganj coal-field coals, and again record my indebtedness to Mr. C. S. Whitworth for kindly placing them at my disposal.

⁽¹⁾ Report on Experiments made with certain coals for coke making, Giridih, 1919.

⁽²⁾ All the coals mentioned by me, except that of Karanpura, are caking coals.

TABLE X
Analyses of coking coals, West Raniganj coal-field

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fixed carbon.....	56.00	54.65	55.70	58.60	48.90	59.00	60.00	59.70	57.60	60.90	59.00	59.90	62.60	62.00
Volatile matter.....	32.75	34.05	32.80	30.60	31.05	32.00	27.60	27.00	25.30	27.85	25.40	27.40	26.00	22.40
Moisture.....	1.35	2.55	2.25	1.48	2.15	2.81	2.10	2.90	2.00	1.52	1.20	1.40	1.40	1.30
Ash.....	11.25	11.30	11.50	10.80	20.05	9.00	12.40	13.30	17.10	11.25	15.60	12.70	11.40	15.60
Calorific value (calories)....	7,300	7,169	7,194	7,504	6,346	7,469	7,194	7,271	6,737	7,387	7,170	7,215	7,632	7,223
1. Dishergarh seam,			Parbelia		colliery		(Andrew Yule & Co.);			analysis by	Alipur Test House.			
2. " "			Methani		"		(Macneill & Co.)			"	"	"	"	"
3. " "			Burra Dhemo		"		(Andrew Yule & Co.)			"	"	"	"	"
4. " "			Barnondia		"		(Balmer, Lawrie & Co.)			"	"	"	"	"
5. Hathnal			Sanctoria		"		(Andrew Yule & Co.)			"	"	"	"	"
6. Sanctoria			Seetalpur		"		(Andrew Yule & Co.)			"	"	"	"	"
7. Begunia			Begunia Khas		"		(Maharajah of Cossimbazar)			"	"	"	"	"
8. Ramnagar			Ramnagar		"		(Martin & Co.)			"	"	"	"	"
9. Borrea (3rd)			Borrea		"		(Balmer, Lawrie & Co.)			"	"	"	"	"
10. Victoria Top seam,			Victoria		"		(Balmer, Lawrie & Co.)			"	"	"	"	"
11. " Middle seam,			"		"		"			"	"	"	"	"
12. " (10' + 17') Bottom seam			"		"		"			"	"	"	"	"
13. " lower (17') Bottom seam			"		"		"			"	"	"	"	"
14. " upper (10') Bottom seam			"		"		"			"	"	"	"	"

The Bokaro Coal-field

This coal-field has an area of 200 square miles and contains a number of workable seams, one of which, the Kargali seam, is from 80 to 130 feet in thickness. "On the east, the seam is divided into well defined sections and the ash content varies from 11.72 to 30.5 per cent. Followed westward, the seam increases in thickness....like most Indian coals.... the slack is generally from $2\frac{1}{2}$ to 4 per cent lower in ash than the 'run-of-mine'. Randall's experiments ⁽¹⁾ with Kargali slack were very successful.... The carbonized product was very dense, fine grained, and extremely hard. It would appear, therefore, that the 'clean product', owing to its high coking qualities, could be used with great advantage in the blending of weak-coking coals. This in itself would increase the reserves of coke-making coals" ⁽²⁾. As reported by Mr. Thomas, a very large amount of slack is produced at the State Railway (Kargali) collieries, and, in view of the lower ash content of this material, he suggests it could be handed over to the iron-masters in exchange for non-coking steam coal. He estimates the amount of this slack at about 10 per cent of the output, which is 200,000 tons a year ⁽³⁾.

The Kargali seam is said to contain 1,000 million tons of coal, of which 600 million tons, according to Dr. L. L. Fermor, are of good quality. Mr. C. S. Whitworth estimated that 485 million tons were of coking quality. After making liberal allowances for faulting, destruction by igneous intrusions, etc., the East, or Gumiya, section (10 square miles) is considered to contain 365 million tons of Kargali coking coal. As a result of analyses made by Randall, the ash content of the Kargali coal has been understood to run rather high, but to some extent this statement needs modification. The following

⁽¹⁾ Randall's experiments on washing Indian coals by means of the froth flotation process; *Rec. Geol. Surv. India*, Vol. LVI, Pt. 3.

⁽²⁾ Contribution by Mr. J. Thomas, *Trans. Min. Geol. Inst. (India)*, Vol. XX, Pt. 4, p. 417.

⁽³⁾ This slack is already being used at Giridih for steam raising, to economize the more saleable Giridih coal from the lower Karharbari seam.

analyses, made by the Alipur Test House and kindly supplied by Mr. C. S. Whitworth, are of coal from the Dhori colliery (Anderson, Wright & Co.):

	No. 6 incline	No. 2 incline
Fixed carbon.....	63.70	62.30
Volatile matter.....	25.50	24.60
Moisture.....	1.10	1.00
Ash.....	11.30	13.10
Calorific value (calories).....	7,507	7,300

These analyses show that the seam contains coal of as good quality as many of the better seams in Jharia. In this connection Mr. Thomas' remark, that "Mr. Randall paid more attention to high-ash coal... than to those of low-ash content. That is why experiments on the better sections of the Kargali seam were omitted", should not be forgotten entirely in the consideration of reserves of coking coal, suitable for metallurgical requirements, from the Bokaro coal-field.

The Assam Coal-field

Although I feel this is not the correct place to discuss the coking coals of Assam — because not only is their distance from the smelters relatively large, but their high sulphur content renders them unfit for the manufacture of metallurgical coke suitable for iron-ore smelting — nevertheless there is always the possibility of a practical de-sulphurizing process being devised which might make them attractive for smelting iron ores locally. I had made a provisional estimate of 90 million tons above ground-water level; however, seeing that pumping is extensively necessary in the Jharia coal-field, Dr. Pascoe inclines to the view that the total can be carried to 600 million tons of workable coal in this region.

Analyses of these coals are as follows:

	Average*	Makum*	Namchik*	Nazira	Jaipur
Fixed carbon.....	60.0	57.47	52.90	57.8	55.0
Volatile matter.....	36.2	40.38	44.4	34.1	34.7
Moisture.....	.....	.....	.....	5.5	6.9
Ash.....	3.8	2.15	2.7	2.6	4.4
Sulphur.....	2.32	?	?	?	?

*Dry basis.

In concluding this Section, I would not be understood to deprecate in any way the reserves of coking coal in the Jharia field. They are the most valuable and the main source of supply of good coking coal in India. What I am endeavouring to make clear is that there are also other, if subsidiary, supplies of suitable coking coal elsewhere in the Bengal coal-fields, which, in view of the pessimistic opinions recently made public, I feel it my duty to advertise perhaps a little prominently. As Dr. E. H. Pascoe, Director of the Geological Survey of India, has said, "I am quite aware that the estimates of coking coal in India must be taken with a large grain of salt. For that matter, so must the estimates of the amount of iron ore. Messrs. Tata & Sons, I know, consider the Geological Survey estimates as excessive. I must not make too much of this argument, however, as it cuts both ways to some extent. For, if the Geological Survey estimates of iron ore are in excess of other estimates, by including more lower-grade ore, it must be remembered that this lower-grade ore requires a better-grade coke".

Reserves of Coking Coal

Summing up the situation as we know it at present, it is possible to say that the Indian reserves of coking coal of good quality which can be used, either alone or by very careful mixing, for the preparation of coke of metallurgical quality, are briefly as follows:

TABLE XI

Quality	Field and seams	Amount in millions of tons (approx.)	Remarks
I. Highest grade metallurgical coke	Giridih lower Karharbari.	9	Specially low in phosphorus and ash. Suitable for making iron of Bessemer quality or ferro of standard grade.
	Total.....	9	
II. Good metallurgical coke	Jharia 13, 14A, 14, 15 and 17.....	732	Good quality coal. Total estimated 1,100 million tons. Allowance 33½%. Best coke from coal slack.
“	Giridih lower Karharbari.	30	Excellent coke physically; sometimes rather high in ash, particularly if made from coal slack.
“	Raniganj Victoria-Laikdih and Ramnagar.	50	This coke has been utilized in the Kulti furnaces. All allowances made; 25 million tons each.
	Total.....	812	
III. Fair metallurgical coke	Jharia 10, 11, 12, 16 and 18.....	800	Some of this coal is as good as Class II. Total estimated 1,200 million tons. Allowance 33⅓%
“	Raniganj Dishergarh.....	48	Best used by carefully mixing with 17 seam or others by experiments. All allowances made.
“	Sanctoria.....	36	
“	Begunia.....	25	
	Bokaro Kargali.....	365	Some of this is known to be of good quality Class II, but there is a little uncertainty about the ash in the remainder. All allowances made.
	Total.....	1274	
IV. Good coking coal, but not of metallurgical quality	Assam fields	600	Very high in sulphur. If this impurity can be removed, this could be included in Class I or Class II.
	Total.....	600	

On the basis of the projected requirements for 1928, *i.e.*, about 4 million tons of coking coal to give $2\frac{1}{4}$ million tons of coke, there is enough coal of Classes I and II to last more than 200 years if used exclusively for iron-ore smelting. On the basis of the production of pig iron in Great Britain under normal conditions, *i.e.*, about 6 million tons of pig iron, the requirements of coking coal will be roughly 9 million tons a year, and the calculated reserves of Classes I and II would therefore last 70 years if exclusively utilized for iron-ore smelting. If the reserves in Class III are included, the reserves of coking coal will last 500 years on the 1928 basis, and 200 years on the British basis.

It is ridiculous to imagine that these coals will be exclusively used for the production of metallurgical coke, but with such large margins there is scope for adjustment. There is time for a gradual re-arrangement in the use of coal for various purposes. By so doing, reasonable economies could be effected, whereby the better grades of coking coal may be conserved. These are matters of official policy on behalf of posterity, and in this particular case our duty is done in drawing attention to the situation, trusting that those who are at the helm of Government will observe the signals and steer accordingly.

OTHER COALS

I feel that, in adding a fresh section on the subject of coal, perhaps the matter is being unduly laboured. However, the object in view is to show that there are large reserves of non-coking and low-grade coking coals in India. It is true that we are confronted with the fact that, compared with the excellent coals of America and Europe, these Indian fuels suffer from two disadvantages: they are relatively much higher in ash, and they decrepitate if exposed to the weather for long. In a broken down condition, also, some of them are very liable to spontaneous combustion.

The coals of the Giridih field are dull coals, generally of good quality, and they do not readily fall to pieces on exposure. They also stand handling tolerably well. The coals of the Damuda Valley coal-fields, on the other hand, have a charac-

teristically banded structure. The bright laminæ (so-called *vitro-clarain* ⁽¹⁾, or *anthraxylon* ⁽²⁾, or *lignitoid* ⁽³⁾) are relatively very low in their ash content. It is these layers which decrepitate rapidly, evidently by oxidation, and add largely to the material of the slack. This is why, unlike the Giridih coal and most British coals, the slack of the Damuda Valley coals is usually lower in ash than the 'run-of-mine' coal. As this slack is more amenable to treatment — washing, froth flotation, and almost certainly float and sink processes ⁽⁴⁾ — it is possible that appreciable quantities of the clean product could be rendered available for coke manufacture.

In the case of the Talchir, Rampur, Korea, and certain other coals of the Mahanadi Valley and South Rewa basin, other features are present. These coals are of a peculiar uniform ebony-wood-like texture. It is not easy at first to tell if the substance is coal or carbonaceous shale. A satin sheen and light weight indicate coal which may be as low as 6 per cent in ash. Other duller varieties yield up to 25 per cent ash, and a distinct dull, earthy, appearance is characteristic of material with 40 to 60 per cent ash. Here, then, is a fuel which would appear to be readily separable into grades by jigs. Most of this material suffers from the great disadvantage of breaking up to smalls on prolonged exposure.

Banded coals of Gondwana (Barakar) age also occur in the Godavari-Wardha Valley and Satpura coal fields. These are normally rather high in ash, due to the predominance of the dull layers. These coals decrepitate somewhat rapidly on exposure. It is possible, therefore, that gravity separations could be effected, but this will mean the discarding of appreciable percentages of the coal, as the dirty products will probably be nearly equal to those obtained cleaned.

In Table XII I have endeavoured to present a statement, a very tentative one, of the available reserves of all kinds of coals in the Indian coal-fields:

⁽¹⁾ "The Microscopic Examination of Bituminous Coal in Polarized Light", by Cyril S. Fox; *The Mining Magazine* for January, 1927.

⁽²⁾ After Reinhardt Theissen.

⁽³⁾ After E. C. Jeffrey.

⁽⁴⁾ Fuel, Vol. V, No. 5, 1926 (May), p. 184; paper on "The Cleaning of Coal", by W. R. Chapman and R. A. Mott.

TABLE XII

Reserves of coal of all kinds in India
(In million 2,240-lb. tons)

Coal-field	Total all kinds of coal	Total coals of coking quality*	All coals other than coking coals*
Giridih.....	60	40	20
Raniganj.....	22,000	408	21,592
Jharia.....	20,500	2,300	18,200
Bokaro Ramgarh....	1,000	600	400 (at least)
Karanpura S.....	75	} Not fully tested }	8,975
“ N.....	8,900		
Aurunga.....	20	.....	20
Hutar.....	9	Said to be some	9
Daltonganj.....	9	.....	9
Korea, Rewa.....	200	.....	200
Sirguja, Korba	} 200	Some in Korba small quantity	
Sambalpur.....			
Talchir.....	44	.....	44
Wardha and Godavari Valleys..	} 400	.....	} 400
Satpura Region.....			
	150	Some, very small amount	150
Assam.....	600	600	There are some
Rajmahal area.	200	Not properly tested	200
Other fields.....	100	?	100
Total.....	54,467	3,948	50,519
Allowing $\frac{1}{3}$ for losses	36,311	2,632	33,679

*Coal which might be suitable for the manufacture of metallurgical coke.

It is seen from the figures in Table XII that the estimated reserves total the huge amount of 33,000 million tons. Taken on purely theoretical grounds, there is enough carbon in all this coal to effect the reduction of the estimated reserves of high-grade hematite-ore in the Iron Belt, not merely once but very nearly ten times over. Yet this carbon is present in an unsuitable form for the requirements of modern blast-furnace practice. I have now fully though briefly stated the case for Indian coals. Their nature and behaviour are as we find

them. These properties do not receive the attention they deserve. On the one hand, consumers of Indian coal for steam-raising purposes will only use the best lump coal, because it has a higher calorific value and does not fall through the fire bars unburned into the ash pits. They demand this quality and grade from the coal producers, who, consequently, have on their hands larger supplies of slack than they can sell, and which, when stacked, is liable to spontaneous combustion. The only suggestion that the purchasers of steam coal can make is that the slack should be briquetted. Perhaps there is no country in such difficulties for fuel as Burma, and yet the local supplies there evidently cannot be briquetted sufficiently cheaply to compete with coal imported from the Bengal coal-fields and then transported all the way up to Mandalay. Briquetting is not cheap because of the cost of the coal tar pitch which is used as a binder. These consumers of coal for steam raising purposes limit their prices and want material to burn under boilers which have been designed for the consumption of lump coals of a higher grade than is generally available from domestic resources. The result is that experiments with the slack coal in pulverized form are, so to speak, wasted if the larger consumers refuse to adopt methods whereby greater thermal efficiency can be obtained from the material which coal vendors would be glad to sell at low prices. On the other hand, the iron-masters in India (as elsewhere — America, Great Britain, France, Germany, etc.) demand coke which is not only of a certain chemical quality but also capable of standing the weight and slide of the charge in the furnace. This is naturally their stipulation — also with a maximum limit to the price. If we remember that, in the processes of smelting, enormous volumes of valuable gases ⁽¹⁾ are allowed to discharge to waste, it is difficult to understand why hard lump coal is not used. If we consider that present blast-furnace practice, except for slight improvements in the mechanical appliances of loading, etc., has remained unchanged

(1) Such furnaces as 'D' furnace at Jamshedpur, or the mammoth blast furnaces of the United States, which cope daily with a charge of 800 tons of iron ore, 400 tons of coke, and 160 tons of limestone, require 1,680 tons of pre-heated air, and produce 400 tons of pig iron, 240 tons of molten slag, and 2,400 tons of hot, dust-laden flue gases. This means 6 tons of gases to every ton of pig iron.

now for very many years, we obtain our clue. It is not to be forgotten that there is not only the loss of sensible heat in these waste gases. They have potential energy also. There is a heat loss in the circulating water to the tuyere nozzles, and in the general radiation from the metal-work sheathing of the furnace. What these heat losses really are can only be appreciated by a fuel engineer who has taken temperature readings of flue gases, of the cooling water, and of the heat radiated from the furnace. Compared with the thermal efficiency of an aluminium reduction plant, the blast furnace for making pig iron is almost extravagantly wasteful ⁽¹⁾. There would appear to be scope, at any rate in India (for the utilization of Indian fuels), for a complete revolution in iron metallurgical practice so as to obtain a higher thermal efficiency in smelting.

Thus we see that the Indian coal-vendor is between two conservative consumers—he is called upon to satisfy the dilettante tastes of the boiler engineers and the epicurean requirements of the blast-furnace managers. However, as Dr. Pascoe has said, there is no more cause for panic than there is for self-satisfied inertia. The consumers of steam coal and the smelters of ores, no less than the vendor of coal, must, each in their respective fields for research, investigate the possibilities of using the Indian coals, as a whole, in as efficient a manner as possible. The use of raw coal appears to be generally condemned today, except, perhaps, in the case of low grades of coal in pulverized form. The coal producer must, therefore, clean those coals which are amenable to amelioration, and study the processes of carbonization and liquefaction of coal. I give below brief notes on (1) the use of pulverized fuel, (2) the cleaning of coal, (3) carbonization methods, and (4) the commercial application of a process for the liquefaction of coal by means of hydrogen.

The Use of Pulverized Fuel

It is unreasonable to expect that the Government of India should launch out in an extensive manner on an elaborate series of tests. Various experiments on washing by the froth

⁽¹⁾ It is true the price of aluminium ingots is about 18 times that of pig iron. It is also true that the pure alumina (Al_2O_3) used in these furnaces is quite 50 times the price of iron ore (Fe_2O_3).

flotation process, and in briquetting, have already been carried out. Arrangements have now been made with the Mining Department of the University of Birmingham for tests with the Salt Range coals in pulverized form. In this connection the following letter from the North Metropolitan Electric Power Supply Company, London, is of considerable interest. They say:

“Our decision to use pulverized fuel for our new power station at Brimsdown is partly the result of practical experience on a small scale, largely on account of a study of the conditions in America, which I visited for this purpose two years ago. Broadly speaking, I think it true to say that, although the capital cost of the boiler house and its equipment would be somewhat higher than with ordinary grates, and the amount of energy required for auxiliary plant is also more, this is more than counter-balanced by the great increase in efficiency and combustion and, more particularly, in continuous efficiency, to say nothing of the great diminution in labour costs. Furthermore, I do not believe it is possible, with large boiler units, to use pre-heated air (which we consider essential) with any type of mechanical stoker. While we have done this successfully with small boilers, the large size of the grates for these bigger boilers has, I believe, already given trouble when pre-heated air has been used; but, of course, such disability does not apply to pulverized fuel.

“We are installing five boilers, each capable of supplying about 100,000 lb. of steam per hour. The coal will be dried and pulverized in a separate building and forced into the pulverized fuel bunkers to the boiler house by means of compressed air. The drying will be carried out by means of live steam.

“There is a great deal of difference, of course, between coals in different parts of one country, but there seems little doubt that the coal with which we have to deal in this country is considerably harder than the American coal, and this naturally makes more work for the pulverizer to do and there is more wear. The coal, however, here is of far more uniform quality than in America, although it

According to Mr. J. Thomas, "The Birmingham Corporation, however, adopted pulverized fuel firing in order to get rid of the dust difficulties by mechanical stoking. Combustion is complete with pulverized fuel, and the air, instead of being laden with particles of soot, is charged with a smaller quantity of very fine particles of completely burnt ash which, owing to its light and spongy nature, is carried away by the atmosphere".

The Cleaning of Coal

Professor E. H. Robertson is reported to have carried out washing tests on Jharia coal from Nos. 13 and 14 seams. The results obtained are quoted by Mr. H. C. Read to be:

No. 13 seam, unwashed.....	16.92	per cent ash
" " washed.....	9.83	" " "
No. 14 seam, unwashed.....	12.12	" " "
" " washed.....	8.71	" " "

He does not, however, state what the recovery of good-quality material was, nor does he give the ash percentage of the residue. The analyses of Giridih coal given on an earlier page (in the section on coking coals) show that there are great variations in the ash content in the vertical section of Indian coals. In the case of No. 16 (Sijua) seam in the Jharia field, the variability is quoted by Dr. Coggin Brown (*Indian Coal Problems*, Calcutta, 1926, p. 19) as follows:

Top coal, not worked.....	6	feet
7th foot.....	60.7	per cent ash
8th "	24.5	" " "
9th "	24.1	" " "
10th "	13.7	" " "
11th "	9.9	" " "
12th "	33.2	" " "
13th "	35.5	" " "
14th "	22.1	" " "
15th "	12.5	" " "
16th "	25.4	" " "
17th "	17.1	" " "
18th "	10.8	" " "
19th "	14.1	" " "
20th "	22.0	" " "

This gives 20.4 as the average percentage of ash in 14 feet of coal.

Read also quotes (from work done by Messrs. Draper and Evans, on clean bright cubes with no shaley interstratifications), the variation of ash percentage of Indian coals, and states the corresponding specific gravity⁽¹⁾:

Sample	Sp. Gr.	Ash percentage
1	1.33	10.15
2	1.34	11.55
3	1.39	12.60
4	1.33	13.20
5	1.37	14.22
6	1.41	14.60
7	1.44	17.50
8	1.46	18.65
9	1.43	18.30
10	1.49	21.32
11	1.60	26.20

It is also interesting to have the corresponding figures for Indian coal-seam shales. These Dr. Brown quotes as follows:

Shale seam	Sp. Gr.	Ash percentage
Malkera	2.0	53.25
"	3.16	71.65
"	2.89	77.65
"	2.42	84.15
"	2.41	85.47
Alkusa.....	2.30	56.50
" (10 seam)	....	46.95
" (16 ")	1.85	45.0

Such data as have been quoted above show that, whereas simple washing may not remove much of the ash, there are great possibilities in *separating components of greater specific gravity than, say, 1.40 in coal of sizes above $\frac{3}{8}$ inch diameter to the size of cobbles*, either by operating with a 'float and sink' method, or by subjecting the screened product to treatment by jigs and vanners. In this latter connection, the following data (very kindly supplied to me by Mr. H. W. Laverick) with regard to the cleaning of some South Yorkshire coal (Parkgate seam) at Tinsley Park colliery, Sheffield, are of considerable interest:

⁽¹⁾ Dr. L. L. Fermor carried out similar investigations several years ago. I understand he proposes to publish them now, together with some detailed chemical analyses of the ash, the composition of which, in high-ash coals, must greatly modify the simplicity of the variation.

I.—Humboldt Washery

	Tons	cwt.	Percentage
Unwashed coal, treated.....	231,680	0	
Dirt washed out.....	21,854	10	11.59
Returns for sale, singles.....	33,174	0	14.32
“ “ doubles.....	40,421	13	17.45
“ “ washed slack.....	19,003	11	8.20
Dry washed slack to coke ovens.....	112,230	6	48.44

II.—Koppers ovens and by-product plant

	Tons	cwt.	Percentage or amount per ton on dry washed coal
Coke, wet.....	85,520	0	76.20%
Sulphate of ammonia (dry neutral).....	1,267	15	25.30 lb.
Tar.....	5,041	4½	8.98 gal.
Benzol (crude 65%).....	300,860	gallons	2.68 gal.

Surplus gas

Sheffield Gas Co.....	462,447,000	cubic feet (unpurified)
Colliery boilers.....	102,485,000	“ “ “
No. 8 boilers.....	794,000	“ “ “
Colliery gas engine.....	25,902,000	“ “ “

The above is one year's working, ending 30th September, 1925. During April, 1925, the whole of the plant was shut down for a week for repairs, renewals, etc., and it was fully ten days before normal working was again established.

Carbonization Methods

The processes of high-temperature carbonization, or normal coking, either in ovens for the manufacture of metallurgical coke or in retorts for the production of gas, are too

Production of Soft Coke, in tons (of 2,240 lb.)

Field		1921	1922	1923	1924	1925
Assam Lakhimpur	{ Soft coke	nil	nil	nil	nil	nil
	{ Hard coke	256	332	409	683	802
	{ Coal used	768	995	1,226	2,048	2,405
Bengal Sontal Parganas	{ Soft coke	...	...	...	...	164
	{ Hard coke	...	...	...	...	nil
	{ Coal used	...	...	...	...	245
Raniganj.....	{ Soft coke	6,967	4,699	8,005	7,521	7,471
	{ Hard coke	1,355	809	747	540	350
	{ Coal used	14,410	9,809	14,509	13,437	12,044
Bihar and Orissa						
Raniganj.....	{ Soft coke	67,770	81,263	93,374	115,442	113,173
	{ Hard coke	nil	86	81	62	39
	{ Coal used	103,277	122,803	144,105	178,985	165,176
Jharia.....	{ Soft coke	71,730	98,859	113,464	176,797	290,807
	{ Hard coke	79,345	89,542	40,720	22,631	21,006
	{ Coal used	260,508	290,723	232,836	309,009	479,909
Bokaro.....	{ Soft coke	4,814	4,017	4,842	4,882	4,328
	{ Hard coke	219	nil	nil	285	302
	{ Coal used	7,709	5,942	7,315	7,941	7,069
Giridih.....	{ Soft coke	nil	nil	nil	nil	26
	{ Hard coke	39,961	42,752	40,884	37,123	32,722
	{ Coal used	53,758	49,637	50,926	48,951	44,113
Central Provinces						
Pench Valley.....	{ Soft coke	...	15	...	100	...
	{ Hard coke	...	nil	...	nil	...
	{ Coal used	...	21	...	150	...

Total soft coke in 1925.....415,969 tons

*These figures do not include metallurgical coke made at the various iron works.

well known to be discussed here. Both processes are in use in India. With regard to the subject of low-temperature carbonization, little is known actually by the public, and too much has been said. The applications are so many that it is best to refer only to the practical utilization of the process, and in this there has hitherto been no great commercial success. In his speech in the House of Commons on June 29th, 1925, the Prime Minister, with all the experience of the Fuel Research Board behind him, said:

“The time has not come yet when a commercial process has been successfully devised. It will come, it may come soon, it may be in a few years, but it is certain as we are standing and sitting in this House this afternoon that what has been proved successful in the laboratory will be proved successful commercially, and when that day comes, although what is discovered in the laboratories must be the common property of the science of the whole world, yet it will give this country probably the greatest push forward in development that it has had since the discovery of steam”.

Here in India, we must also wait. That there is a demand for smokeless fuel will be evident from the statistics (see p. 228) on the consumption of ‘soft-coke’ or ‘poora koela’ in Calcutta and other large cities bordering the Bengal coal-fields and elsewhere.

Most of the coal utilized in India for the manufacture of ‘soft coke’ is fuel of relatively inferior grade. The existence of a market for this material is therefore fortunate. The method of making this soft coke, usually in open heaps by the road-side, leaves scope for the production of large quantities, together with a recovery of the by-products now lost, by any successful process of low-temperature carbonization. Experiments have already been conducted in India on a commercial scale—the Neilson sensible-heat process on behalf of Carbon Products, Ltd., in 1924, and certain attempts at Kustore colliery on behalf of the Coal Products Syndicate in 1920. Neither of these trials has yet led to a commercial production. Analyses of the Toposi coal used at Kustore are of interest (after Edgar C. Evans):

	Lump coal	Small coal	'Soft coke' produced (dried sample)
Fixed carbon.....	46.85	46.41	65.57
Volatile matter.....	37.17	36.39	4.58
Moisture.....	3.10	2.94	.....
Ash.....	12.87	14.26	29.85

The average composition of the soft-coke, or '*poora-koela*', made by indigenous methods in the Raniganj coalfield is given by Dr. Brown as:

	Toposi			Kalipahari		Jote Janak	
Fixed carbon.....	63.84	73.92	60.07	64.37	56.22	71.14	65.00
Volatile matter...	7.12	6.18	8.11	7.21	5.78	5.34	6.00
Moisture.....	3.75	8.00	10.40	5.37	5.52	6.70	6.10
Ash.....	29.04	19.90	31.32	28.42	38.00	23.52	29.00
Sulphur (approx.)	0.20	0.26	0.26	0.25	0.25	0.28	0.28

The subject of smokeless fuel also has a curious interest in India, from the fact that there are hundreds of acres of coal in the Jharia and Raniganj coal-fields which have become coked into natural-coke, or *jhama*, as a result of the intrusion of sills of mica peridotite. In one case of which I have details to hand (No. 14 seam, Jharia, at Bhalgora colliery), the analyses of the undamaged coal, and of the *jhama* produced from it by a sill, are shown below:

	Nodular coal No. 14 seam	Jhama of coal in No. 14 seam
Fixed carbon.....	67.46	73.68
Volatile matter.....	24.63	11.34
Moisture.....	0.95	1.41
Ash.....	6.96	13.57
Sp. Gr.....	1.34	1.42

In the case of two natural cokes from the same seam (No. 4) near Borrea colliery, in the Raniganj coal-field, the analyses were:

	Coal	Jhama 2 ft. sand-stone between coal and intrusive rock		Jhama near contact with intrusive rock	
	1	2	3	4	5
Fixed carbon.....	50.56	59.76	57.04	69.75	56.13
Volatile matter.....	29.45	20.89	21.55	8.22	13.68
Moisture.....	1.47	0.93	1.15	1.10	1.96
Ash.....	18.52	18.42	20.15	20.93	28.23
Sp. Gr.....	1.39	1.46	1.48	1.60	1.68

Nos. 1, 3 and 5: Specimens collected by E. R. Gee and analysed by A. K. Banerjee, Geological Survey of India.

Nos. 2 and 4: Specimens collected in the same quarry by C. S. Fox and analysed in the Geological Survey Laboratory.

There is estimated to be several million tons of this natural coke in the various seams of the Damuda Valley coal-fields—particularly Jharia and Raniganj—an attractive quantity being reported in No. 13 seam between Bhalgora and Simlabahal. The question of extracting this material for purposes of generating power (by gas producers, etc.) has been considered. It is thought that, as this fuel has no cleat and is hard—every pound of it will have to be laboriously won—the cost of working it will be at least Rs.2/—, perhaps much more, per ton above the normal expenses involved in getting coal in the same collieries. It is this matter of only an extra Rs. 1/— which militates against the adoption of sand stowage in the more valuable undamaged seams. Thus it would appear that the subject of utilizing these attractive occurrences of natural coke must also await the commercial prosperity of the future. But the wait cannot be indefinite, for if coal seams *below* such naturally coked seams are worked and de-pillared, the resulting subsidence will destroy all hope of winning the over-

lying jhama. However, there is a prospect, judging by Dr. Penman's remarks, of de-pillaring operations being delayed some time. Should sand-stowing be adopted, these jhama seams will be saved to posterity.

Fluid Fuel from Coal

Notwithstanding the various devices and processes for improving the quality of poorer coals so as to obtain enhanced thermal results and better prices, the modern tendency is against the use of raw coal for direct combustion. The manufacture of producer (Siemens) gas, and mixed or semi-water (Dowson's) gas, are well known processes for the conversion of coal into a fluid fuel. Coke-oven gases are of no less value, but the gases from the greatest gas producers of all—the blast furnaces—appear to have been strangely neglected until recent years. The potentialities of utilizing these gases for the preparation of liquid hydrocarbons by hydrogenation in the presence of a catalyst such as cobalt or iron have been recognized by Dr. Franz Fischer and his co-worker, Dr. Tropsch. These investigators, however, have been studying the synthesis of petroleum by experimenting with purified technical water gas. They have found that by hydrogenating carbon monoxide under pressure at high temperatures, in the presence of nickel or alkalized iron as a catalyst, hydrocarbons cannot be produced—the products are invariably oxygen compounds such as higher alcohols, ketones, and aldehydes with some higher fatty acids to which they gave the general name of 'synthol'. By treating water-gas with hydrogen under normal pressures at temperatures from 200°C. to 300°C. in the presence of cobalt, they have produced hydrocarbons—namely gasol⁽¹⁾, gasoline, and vapours of petroleum and solid paraffin. These chemists have claimed, in a recent lecture ⁽²⁾, that approximately a 50 per cent yield can be obtained with a single passage over a good contact. Dr. Fischer is reported to claim that it "is relatively easier to achieve the synthesis of solid paraffin

⁽¹⁾ A mixture of ethane, propane, and butane.

⁽²⁾ Dr. Franz Fischer's address before the International Fuel Congress, Pittsburgh, Nov., 1926: 'The Synthesis of Petroleum' (The Mining Journal, Dec. 18th, 1926, p. 1038).

than to perform that of gasoline....As to the absolute yield, more than 100 grams of solid, liquid, and easily-liquefiable hydrocarbons to each cubic meter of water-gas can be obtained if the gas is conducted several times over the contact". These most interesting experiments are still being conducted, but they have gone far enough to prove that coal (coke) products (water-gas) can be utilized for the synthetical production of petroleum. General Patard and M. Audibert, in France, have also carried on considerable experimental work at Lenz to establish a commercial process for the synthesis of motor fuel from carbon monoxide and hydrogen.

Dr. Frederick Bergius ⁽¹⁾ rightly considers that since, "in a normal bituminous coal, the ratio between carbon and hydrogen is about 16 to 1, and in a liquid oil about 8 to 1, it follows that in order to transform coal into oil the hydrogen quantity has to be doubled. Hydrogen being an expensive material it is important to conserve as much as possible of the original hydrogen content of the coal.

"But the distillation process, as well as the synthetical process, works precisely in the opposite direction. The distillation process delivers fairly large quantities of free hydrogen out of coal; the synthetical process separates the hydrogen and the carbon completely. In the latter process, coal is transformed into coke, and coke in turn is transformed into carbon monoxide, which means that hydrogen is not only separated from carbon but that oxygen is added to carbon. The carbonic oxide is brought into reaction with new, specially manufactured elementary hydrogen, which is partly consumed for binding the oxygen and partly added to the carbon to establish the proper proportion mentioned before..... liquefaction of coal involves more or less a competition between two reactions—the reaction of hydrogen additional to the coal substance and the reaction of destructive distillation of coal The hydrogenation of coal

⁽¹⁾ Dr. Frederick Bergius' address before the International Fuel Congress, Pittsburgh, Nov. 15th, 1926: "The Transformation of Coal into Oil by means of Hydrogen" (The Mining Journal, Dec. 11th, 1926, p. 1012.)

begins at relatively low temperatures⁽¹⁾. Treated for some hours at a temperature of 300 to 500 degrees, the product is still solid, but has taken up a fairly large amount of hydrogen, and is transformed into a sort of pitch with a fairly high melting point. This product becomes liquid if treatment is continued at a temperature of 420 degrees. . . . Experiments show the yield of oil varies from 40 per cent to 70 per cent according to the various sorts of coal. . . . one short ton of coal yields from 107 to 185 gallons of oil. . . . only anthracites, the real anthracites, cannot be hydrogenized. . . . it became possible to begin the erection of two big factories for coal liquefaction in Germany—one in the lignite territory, under the auspices of the dyestuffs groups, especially the Badische-Anilin-und-Sodafabrik, the other in the Ruhr territory, by the Gesselshaft fur Teer Verwertung, under the management of Dr. Spilker. The total production of both these factories will be nearly 1,000,000 barrels a year of the different oily products out of coal."

FLUXES

The normal fluxes for the iron industry are, of course, limestone and dolomite. The relative infusibility of magnesia means that somewhat higher furnace temperatures must be employed when dolomite is used. This entails a greater consumption of fuel, but it is said that there is an advantage from the higher temperature—this is in a more complete removal of sulphur from the charge, resulting in a lower percentage of this undesirable constituent in the metal produced. Be this as it may, the normal procedure at the Bengal Iron Co. (Kulti), and at the smelters of the Indian Iron and Steel Co. (Hirapur), is, I think, to use limestone mainly, if not entirely. The Tata Iron and Steel Co., up to 1922, favoured the use of dolomite in their blast-furnace charges, as seen in the accompanying Tables, A and B; but, as these data show, limestone has been used in increasing quantities since that time, and I am given to understand that the Tata Company are entirely

⁽¹⁾ The reaction by means of hydrogen is conducted under very high pressure — 200 atmospheres or 2,200 to 3,000 lb. per square inch.

TABLE A

Raw materials utilized by the Tata Iron and Steel Company
for pig-iron production
In tons (of 2,240 lb.)

	1920	1921	1922	1923	1924	1925
Iron ore.....	360,015	453,059	357,231	613,410	865,332	...
Coke.....	320,336	397,743	337,690	544,990	672,789	...
Dolomite.....	144,467	185,543	152,219	224,502	272,763	248,478
Limestone.....	3,668	...	...	44,885	75,898	97,761
Pig iron.....	221,606	281,541	227,683	392,135	540,140	...

TABLE B

Limestone and dolomite used by the Tata Iron and Steel Company
for steel furnaces
In tons (of 2,240 lb.)

	1920	1921	1922	1923	1924*	1925
Open hearth.....	L 23,857	34,280	32,127	39,400	...	12,344
	D 13,331	18,943	15,379	15,360	...	24,068
Duplex plant.....	L .....	...	...	202	...	54,046
	D .....	...	...	701	...	6,117
Miscellaneous.....	L .....	...	...	...	...	446
	D .....	...	...	...	...	33

*Not secured.

changing their blast-furnace practice and adopting the practice of Kulti and Hirapur, *i.e.*, to use limestone. Their shipments of dolomite will in future be entirely for refractory purposes for their steel furnaces. It is the practice at Jamshedpur to use moderately large amounts of fluorspar for fluxing purposes; 802 tons were so used in the steel furnaces in 1925. And advantage has been taken, by the Kulti smelters, of the fact that the addition of a percentage of phosphorus, above that present in the coke, by the introduction of apatite, gives

a phosphoric pig iron which, being relatively more fluid than normal pig iron, is very suitable for the production of sharp-edged and fine castings.

Limestone

Analyses of typical Indian limestones are given in Table XIII. Dr. L. L. Fermor⁽¹⁾ drew attention to the many valuable occurrences of high grade limestone in India, and remarked on the paucity of data regarding their phosphorus content. We are not much advanced since then, but, in a general way, it can be said that Bisra⁽²⁾ limestone contains approximately 0.015 per cent of phosphorus. An analysis of the average material obtained by the Indian Iron and Steel Co. from the Bisra Stone Lime Co. is:

CaO.....	47.30 per cent
MgO.....	4.20 “ “
SiO ₂	3.94 “ “
Al ₂ O ₃	2.41 “ “
Fe.....	0.20 “ “

These vendors of limestone and dolomite supply their material from quarries near Birmitrapur in Gangpur State. The present annual output from these deposits is estimated by Dr. Spencer to be 120,000 tons (4 per cent max. SiO₂) of dolomite, and 120,000 tons (5 per cent max. SiO₂) of limestone. He says⁽³⁾: “The reserves of stone are very large and the present output is limited only by the demand. It is probable that the Gangpur limestone-dolomite anticline will be able to supply the greater part of the fluxstone requirements of the iron and steel industry for many years to come”. The Bengal Iron Co. obtain their supplies of limestone from Baraduar as well as from Paraghat in the Bilaspur district. The Tata Iron and Steel Co. have arrangements for supplies of

(1) “The Manufacture of Calcium Carbide”; Indian Munitions Board Handbook, 1919, pp. 231-233.

(2) I use this term for convenience. It should perhaps be called Gangpur limestone or, from its geological age, Cuddapah limestone. It is, however, most extensively worked by the Bisra Stone Lime Co. of Birmitrapur. The Bisra-Rourkela quarries have not been worked since 1920.

(3) *Trans. Min. Geol. Inst. (India)*, Vol. XX, pt. 4, 1926, p. 346.

TABLE XIII
Analyses of Indian Limestones and Dolomites

	1	2	3	4	5	6	7	8	9	10	11	12
Calcium carbonate.....	98.6	95.4	95.6	95.18	53.57	95.80	91.80	96.03	94.65	45.05	63.40	83.43
Magnesium carbonate.....	0.55	1.81	...	1.57	43.77	2.25	1.70	1.75	2.98	11.53	14.41	0.78
Silica.....	...	0.58	2.25	1.87	2.50	2.70	5.15	1.15	1.79	39.28*	19.28*	16.18*
Alumina.....	...	1.72	2.10	1.04	0.70	0.80	0.52	0.96	...	0.28	0.62	...
Ferric oxide.....	...	0.49	...	0.34	1.00	...	0.32	0.11	0.58	3.64 [⊕]	4.15 [⊕]	0.68 [⊕]
Other constituents.....	...	...	trace	...	...	...	0.35†	...	...	0.07 [⊙]	0.12 [⊙]	0.02 [⊙]
Phosphorus.....	...	...	...	...	...	...	...	...	...	...	...	...

*Insoluble residue.

†Ferrous oxide 0.25, moisture 0.10.

⊕Phosphoric acid.

⊕Ferrous carbonate

1. Chela limestone, mouth of Bogapani river, Khasia hills, Assam.
2. Sylhet (Kirthar) limestone, Assam.
3. Kandara, Chanda district, Central Provinces.
4. Bisra (Cuddapah) limestone, Gangpur State.
5. Bisra (Cuddapah) dolomite, Gangpur State; previously used by Tata Iron & Steel Co.
6. Bisra (Cuddapah) limestone, from Paraghat and Baraduar; used by Bengal Iron Co.
7. Sutna (Upper Vindhyan) limestone, Rewa State, Central India.
8. Maihar (Upper Vindhyan) limestone, Maihar State (Rewa), Central India.
9. Katni (Lower Vindhyan) limestone, Jabalpur district, Central Provinces.
10. Panchet Hill (Upper) } These limestones were previously used by the Barakar Iron Works at Kulti at the time when
11. " (Lower) } the local ironstones of Ironstone Shales were used as the chief ore
12. Hanspathar.

limestone from the Birmitrapur quarries (through the Bisra Stone Lime Co.) for their blast furnaces, but they still contract with the limestone suppliers of Katni (B. N. Railway) and Jukehi (G. I. P. Railway) in the Jabalpur district, and also obtain material from their own quarries at Baraduar. They formerly obtained limestone from Sutna, or Maihar, but these supplies appear to have been discontinued. Much of this material from the more distant localities of Baraduar, Katni, and Maihar is for open hearth use. This question of a long freight haul on a comparatively cheap substance like limestone, unless specially low rates are obtained, puts many other good Indian limestones beyond the reach of the smelters of Jamshedpur, Kulti, and Hirapur. Thus the limestones of Assam are much too far away. They are burned to lime in Sylhet, and this product finds a ready sale for engineering purposes in Calcutta.

In the iron-ore areas of Chanda and Drug, in the Central Provinces, there are quite valuable local limestones—in the former district there is the limestone of Kandara, an analysis of which is given in Table XIII; while in the latter district, the limestone of Dalli is reported to have the following composition:

Calcium carbonate.....	83.5 per cent
Magnesium carbonate.....	2.0 “ “
Silica (insoluble residue).....	13.6 “ “
Alumina and ferric oxide.....	0.9 “ “

The limestones of Rhotas, in the Sone valley, are a continuation of the Vindhyan formation from the Katni vicinity—a distance several hundred miles. These limestones of Rhotas and Sassaram, in the Shahabad district, are closer to the Damuda coalfields than are those of Bilaspur or the more distant Jabalpur district, but they are evidently not suitable (perhaps only in price) for the purposes of the iron and steel furnaces.

From private enquiries, it would appear that the future supply of good, *uniform quality* flux is still a matter of great concern to the smelters. I understand that, if obtainable at a reasonable price, limestone with as much as 6 per cent

silica would be accepted if it could be supplied without much variation in quality. The problem is not whether the Indian reserves of limestone suitable for flux are sufficient, but of the supply of a material of good, uniform grade at a low price. It is thus evident that a large deposit of limestone or dolomite of great purity, if found nearer to the iron smelters than the existing sources of supply, would be very valuable. Failing such a discovery, the freight on limestone for iron-smelting purposes only may require consideration in the near future; but with this I am not here concerned.

The finding of a conveniently located deposit of limestone, however, calls for a word of remark, and in this connection I would draw attention to the bands of crystalline limestone, of considerable thickness, which were reported by the late Dr. V. Ball as occurring between the villages of Olherpat and Deredag, on the eastern edge of the Aurunga coalfield. La Touche says of the marble that it "is of great purity, yielding 91.9 per cent of calcium carbonate." This occurrence has evidently not been recently examined because it lies in an area at present subject to boundary disputes, nor have we particulars as to the nature and amount of the impurities in this limestone. It is, nevertheless, an occurrence which should not be forgotten, and it may repay investigation by iron smelters. Another massive deposit of limestone, probably a dolomite, which also was located by Dr. Ball, occurs in the Maila river, half a mile east of Sathbarwa, in the Palamau district. Both the above-mentioned occurrences of limestone would, if the quality and quantity were proved suitable, assume an importance greater than any of the other limestone deposits which have been referred to, because the projected railway from Asansol to Katni is to cross the Damuda-Sone watershed in the vicinity of the Aurunga coalfield.

Dolomite

As stated previously, the Tata Iron and Steel Co. are discontinuing the use of dolomite as flux in their blast furnaces—an entire change in their smelting practice. They, however use some dolomite, but chiefly for refractory purposes. I am informed that they have re-opened their Panposh quarry,

but they have evidently discontinued the working of their quarries on 'K' lease near Kansbaha station (B. N. Ry.). They have also stopped taking dolomite from the Bisra Stone Lime Co. of Birmitrapur, although they have arranged to take certain quantities of dolomite from near Kalunga station (B. N. Ry.), through B. P. Byramji & Co.

It is only when we turn to the subject of refractory materials, therefore, that the question of the Indian reserves of dolomite will need scrutiny. At present, it has not been thought necessary to enquire into the location of the available supplies, but it is known that many of the marbles in India are dolomitic—for example, the material at the Marble Rocks near Jabalpur. This locality is very little further than Katni, so that, in the remote event of a shortage from Gangpur State, this material could be worked.

Apatite

This mineral, a phosphate and fluoride of calcium, has been worked for several years in the belt of country which stretches for 12 miles southeastward from Pathalghora, through Musaboni, Kanyaluka, and Sungri to Khejardari, in the Dalbhum district. Till recently, most of the output of apatite has been utilized by Messrs Shaw, Wallace & Co. for the manufacture of the fertilizer known as 'superphosphate'. The iron smelters of Kulti have found in this apatite a useful ingredient for their furnace charges when the production of a phosphoric pig-iron is desired. This type of pig iron, as previously stated, has been found particularly suitable for those foundry purposes in which a very fluid metal is necessary. The annual consumption of apatite in the existing iron works has so far been comparatively small—400 to 500 tons—but a very large increase, up to 6,000 tons, so it is said, is anticipated very soon. Although there are no estimates regarding the total reserves of apatite in the Musaboni phosphate belt, I am informed that there are at least 250,000 tons of apatite-bearing rock at a shallow depth in the existing workings between Musaboni and Sungri. If the whole of this material is conserved for the production of phosphoric pig-iron, and a yearly supply of 6,000 tons is consumed, there is enough apatite for

nearly fifty years in the Sungri deposits alone if there is no loss in extraction and the quality is maintained. Prospecting is in progress, and other workable deposits have been found, but their extent remains to be proved.

Fluorspar

Numerous small occurrences of fluorspar are known in India, but so far no workable deposits have been discovered. The Tata Iron and Steel Co. at one time, recently, endeavoured to exploit an occurrence at Barla, in Kishengarh State, Rajputana, but found that the quantity of proved reserves was not very attractive and that the cost of working was so high as to make the domestic fluorspar more expensive than the imported material. The Indian imports of fluorspar, as flux for steel-makers, are estimated at 400 tons annually. An expansion in the steel industry will naturally lead to a greater demand for fluorspar, unless a substitute can be provided from domestic resources.

MODIFYING METALS

The present period of the world's progress will, it is thought, be looked back upon as the *Age of Steel*. It is certainly the era of special steels. Attention is frequently drawn to those high-speed tool steels, containing tungsten or molybdenum, or both these metals with smaller amounts of manganese, which are so hard and tough that they maintain their temper even when red hot, and have by this valuable property revolutionized modern machine-shop practice throughout the world. There are numerous types of steel now available, each possessing some remarkable physical characteristic which makes it practically indispensable for certain purposes. These results have in nearly all cases been obtained by alloying steel with various proportions of other metals.

In some cases the added metal acts simply as a modifying agent and induces definite physical characters in the original steel. Among the metals of this class (I) may be mentioned chromium, cobalt, molybdenum, nickel, and tungsten.

In other instances, the included metal acts both as a modifying agent and as a purifying ingredient. Under this class (II) are to be included manganese, uranium, vanadium, and the non-metal silicon.

In yet a third group come those metals which appear to act only as purifying ingredients of the steel. They can almost be termed fluxes rather than modifying metals in the sense here intended. Examples of this class (III) are the metals aluminium and titanium.

It has generally been found impracticable to use the above mentioned modifying metals in a pure metallic condition, the normal metallurgical practice of to-day being to prepare alloys, usually ferro-alloys, of them and to use this material. The manufacture of these alloys is a highly specialized branch of the metallurgical industry, and it is in this branch of the metallurgy of iron and steel that the raw materials of the several metals which have been named, are directly used. The raw materials generally required for the production of these alloys are discussed below under the names of the various modifying metals.

Class I

Chromium:

Chromium ore, or chromite, is obtained in India in the vicinity of the Zhob and Pishen valleys, in Baluchistan; in the Kadakola and other districts of Mysore State; and near Chaibassa in Singhbhum, Bihar and Orissa. Almost the entire Indian production of chromite appears to be exported. The Tata Iron and Steel Co. used 1,528 tons in 1924 and are using this material for making chromite bricks. Details of the annual production of chromite from mines and workings in British India are given in the *Introduction* of this paper and further remarks will be found in the chapter on refractory materials. There are no particulars regarding the probable reserves of chromite in the various areas named, but judging by the steadiness of the yearly production, it would appear that the available resources of the country will be sufficient to meet any domestic demands for very many years.

Cobalt:

Although cobalt has been detected in the chemical analysis of certain minerals, no cobalt ores have been found in India. The chief sources of the world's supply of cobalt are obtained from Cobalt, Ontario, Canada. Valuable deposits have been located in New Caledonia; in the Katanga region of the Belgian Congo; and elsewhere. It is almost certain that India will always be an importer of cobalt, should this metal be required in a large domestic electrical industry—particularly in the manufacture of steel magnets having a B.H. max. above 600,000.

Molybdenum:

Molybdenite, and, to a lesser extent, wulfenite, are the principal ores of molybdenum. Occurrences of both these minerals have been found in India, chiefly in Burma, but so far none of the deposits have proved to be of great economic value. A little molybdenite had been mined, chiefly with other minerals, in Lower Burma, but the output does not seem to have been maintained. Most of the world's molybdenum ores are obtained from mining regions in Queensland and New South Wales.

Nickel:

No nickel ores of economic value have been proved to exist in India. Interesting occurrences of minerals in which nickel has been detected are given in LaTouche's *Index*. Almost 95 per cent of the world's production of nickel ore comes from the Sudbury deposits of Ontario, Canada.

Tungsten:

The chief ore of tungsten is the mineral wolframite. Wolframite has been found and worked in a small way near Kalimati in Singhbhum, and at Agargaon in the Central Provinces, but these deposits are insignificant when compared with those of Lower Burma. Dr. Coggin Brown says:

“In the Tavoy district—which is the centre of the Burmese wolfram-mining industry, the mineral was rediscovered by the Geological Survey of India in 1909.

Mining commenced in 1910, and in 1911 an output of 1,300 tons made Burma the chief wolfram producing country in the world, a position she maintained till 1916 when the boom caused by the war caused the production of the U.S.A. and Bolivia to surpass hers. By 1917, large quantities were also being produced in China. The wolfram deposits of Burma were of supreme importance to the Empire during the war and between 1914 and the Armistice no less than 17,642 tons, of a total value of £2,323,000, were exported. Of this quantity, over 14,000 tons came from the Tavoy field."

In the absence of estimates of probable reserves, and because of the decline in production during the last few years, the opinion has been expressed that the easily-won deposits are becoming exhausted. However, as Dr. Coggin Brown says:

"The potentialities of the ore deposits are not to be judged by the present outputs during a slump period. Although but little real underground development resulting in the actual proving of ore in sight has been done, the area covered by the producing mines is so large, the wolfram-bearing veins are so numerous, and the eluvial surface deposits are so widespread, that no hesitation is felt in stating that there is sufficient wolfram in Burma to meet any demands which the steel industry in India is likely to make on its resources within the near future, as far as the present-day uses of the element tungsten are concerned".

Class II

Manganese:

Manganese is added to steel in the form of alloys of iron, either that known as *spiegeleisen*, which contains 20 to 30 per cent Mn, and is made from low-grade manganese ores, or *ferro-manganese*, which may contain from 70 to 80 per cent Mn, and requires high-grade ores for its preparation.

The importance of Indian manganese-ore will be appreciated when it is said that the world's yearly production of manganese ore amounts to from 1,750,000 tons to 2,000,000 tons,

of which India, as chief producer, supplies at least 30 to 40 per cent. It is estimated that over 90 per cent of the world's output of manganese ore is utilized in the preparation of spiegeleisen and ferro-manganese for the steel industry. However, of the 600,000 tons, more or less, of manganese ore produced each year in India, perhaps less than a one-twentieth part is utilized by the domestic steel industry; the remainder is exported.

Analyses of manganese ore as received at Middlesborough (1897-1906)
(See Mem. Geol. Surv. India, XXXVII, pt. 3, 1909, p. 517, etc.)

Mn	Fe	P	Moisture	Source
50.49	6.26	0.126	0.72	India.
45.28	0.76	0.147	8.67	Russia, Caucasus.
44.6	3.35	0.046	11.35	Brazil.
47.51	0.41	0.015	1.01	Chili.

Buyers stipulations* as regards manganese ore from India
(After Fermor, in 1909)

Mn	Fe	P	Silica	From
52 to 54	4 to 6	0.07 to 0.08	6 to 7	Nagpur, Balaghat, Bhandara, C.P.P. Syndicate.
51 to 52	6 to 7	0.09 to 0.11	7 to 8	1st grade, Nagpur, Bhandara, C.I.M.Co.
46 to 48	6 to 8	0.03 to 0.17	9 to 11	2nd grade, Nagpur, Bhandara, C.I.M.Co.
50 to 52	5 to 6	0.11 to 0.14	6 to 8	Nagpur, C.I.M.Co.
44 to 46	13 to 16	0.05 to 0.06	2 to 6	Sandur, Jambon et Cie.

*Manganese ores, evidently in limited quantities, have been found in India with less than 0.1 per cent of phosphorus, but apparently no guarantee is now (1926) given that ore will be supplied with less than 0.12 per cent of phosphorus.

The average annual production of Indian manganese-ore has, for nearly 20 years ending 1923, been remarkably steady at about the figure 600,000 tons. In 1907, the output was

nearly a million tons, and it exceeded 800,000 tons during the years 1924 and 1925. An impression has grown to the effect that the Indian production reached the limit of the output capacity of the mines in 1907, and that a general exhaustion of workable resources has since been in progress. This is, of course, disproved by the statistics given. The inability of the mining companies to take fuller advantage of boom periods has been advanced as further evidence that the supplies of ore are diminishing. Those acquainted with the manganese industry know that the unsatisfactory condition of the labour supply, and to some extent the limited transportation facilities, have been most largely responsible for the restricted volume of the annual production. In this connection, it may be stated that Dr. Coggin Brown's remarks, previously quoted with regard to the tungsten resources of Burma, are largely applicable to the manganese reserves of India.

We know very little about the probable reserves of manganese ore in the various deposits⁽¹⁾—including those of the Central Provinces, the area of most intensive mining and largest production. But gauging a country's resources by the annual production over a period of years should provide evidence for confidence or alarm. As stated previously,

(1) If the available information be carefully examined we find that:

- (1) Practically all the manganese ore has so far been won from relatively shallow workings—diggings and quarries, in which water difficulties during the wet monsoon period make the operations very costly at a moderate depth.
- (2) Except in a very few cases, ore has not been proved by boring or mining to a greater depth than 150 feet from the surface.
- (3) The larger deposits have frequently shown a decided tendency to thin out downwards, although surface occurrences are common.
- (4) The Kajlidongri mine, in Jhabua State was, when opened, considered to be promising, and was optimistically estimated to contain ore reserves of 837,000 tons within 50 feet of the surface. This mine closed down in 1915, but has been re-opened since.
- (5) The mines of Sandur State, Madras Presidency, were estimated to contain available ore reserves of perhaps as much as 10 million tons. The ore was thought to be of poor quality and the mines were practically closed down in 1914. Since 1921, when the output was 567 tons, the production has steadily risen—1,470 tons in 1922, 37,318 tons in 1923, 43,809 tons in 1924, and 52,576 tons in 1925.
- (6) In the Vizagapatam district, the output in 1914 was 26,000 tons. During the war period the output declined until, in 1920, it had fallen below 5,000 tons. Since then, production has recovered being 22,524 tons in 1923, 31,811 tons in 1924, and 26,909 tons in 1925.

India furnishes nearly 40 per cent of the world's supply of manganese ore. The Indian production for the past 20 years is shown below:

Five-year period	Average per year (In tons of 2,240 lb.)
1904-1908	509,143
1909-1913	712,797
1914-1918	577,457
1919-1923	624,635

In 1924 the output was 803,006 tons, and in 1925 it amounted to 839,461 tons.

In conclusion, it may again be stated that, from the standpoint of domestic demand, the manganese-ore deposits can be estimated as almost inexhaustible, but so far as the export trade is concerned, the time appears to be ripe for more information regarding the continuation of the ores in depth. The annual production of manganese ore has been remarkably steady through various periods of fluctuation in the world's

-
- (7) Mysore State maintained an average annual production, during the five-year period 1921 to 1925, of roughly 24,000 tons from the Shimoga district (the Kumsi mine was, in 1907, credited with reserves of 300,000 tons within a depth of 50 feet from the surface), and Tumkur and Chitaldrug. The output from each area varies considerably, although the total for the whole State is steady.
 - (8) The output from the manganese mines in Singhbhum and Gangpur State (Bihar and Orissa) increased from 2 tons and nearly 3,000 tons, respectively, in 1916, to 500 tons and over 21,000 tons, respectively, in 1920.
 - (9) In the Bombay Presidency, the output from the Panch Mahals was 46,041 tons in 1924 and 52,069 tons in 1925, as against 34,000 tons in 1920; while the production of Chota Udepur has fallen from 30,000 tons in 1920 to 10,142 tons in 1924 and 6,805 tons in 1925. The Belgaum ores, on the other hand, for a time disappeared from the market—the output in 1924 being *nil*; but in 1925 it is given as 3,604 tons.
 - (10) With regard to the Central Provinces, where the greatest mining development is in progress, there are no calculations available as to the quantities of proved, probable, and possible ore in reserve in the various mines. (a) The Jabalpur district for a few years recently was not shown as a producer, but in 1925 the output was 1,901 tons. (b) In the Balaghat district, the best area in India, nearly 3 million tons of ore have been produced to date. The mines of this district have maintained an average production of about 250,000 tons per annum during the period 1921 to 1925. In 1922 the output fell to 169,182 tons, but in 1924 it was 270,157 tons and in 1925, 262,450 tons. The workings at Ukua have been accumulating stocks, chiefly from

markets. I do not understand this, and do not like such features which I do not understand. Dr. Fermor⁽¹⁾ says that "without the discovery of new deposits, a decline must, however, eventually set in; and whilst this time may be somewhat distant, nevertheless I thoroughly agree with Dr. Fox that it is high time that the continuity in depth of the Indian manganese-ore deposits were thoroughly proved by boring".

Uranium:

Nodules of pitchblende, associated with uranium-ochre and triplite, were discovered in a pit at the Abraki Pahar mica mine near Singar, in the Gaya district. The largest nodule found weighed 36 lb. The Indian production of pitchblende in 1913 was 6 cwt., all from this locality. In 1914, the output had fallen to 16 lb., and there have been no subsequent returns. Green and yellow encrustations of uranium compounds have been noted in exposures in the apatite belt of Dhalbhum, near Sungri.

pickings on the surface, for many years, and probably have about 150,000 tons stacked; but the workings did not appear remarkably rich when I saw them four years ago. Stocks of ore also lie within 2 miles southeast of Laughur bungalow, but they are not so large, although good ore is seen *in situ*. The Balaghat mine (Bharweli) is said to be the best in the district, but we have no details as to the ore reserves there, nor are there particulars as to the resources of the mines at Thirori, Ramrama, and Katangiheri. (c) The manganese-ore output from the Bhandara district was 82,000 tons in 1914, but fell to a little over 32,000 tons in 1918, owing to a readjustment of district boundaries in 1917, whereby some of the deposits were transferred to the Balaghat district. Since then the production has again risen (91,000 tons in 1920), due to intensive mining of the deposits left in Bhandara. The most extensive outcrops in this district are those of Kurmura, Chikhla and Sitasaongi. Here again we are dealing only with surface digging. (d) In the Nagpur district, the output previous to 1921, with fluctuations, averaged roughly 150,000 tons a year, but in 1920 the production was 222,000 tons and in 1924 and 1925 it has been 204,521 tons and 216,484 tons, respectively. The output is obtained from numerous workings at the following localities: Kodegaon, Gumgaon, Kandri, Mansar, Beldongri, Lohdongri, Kacharwahi, Waregaon, Mandri, Manegaon, Guguldoh, etc. I have not been able to obtain any details of the probable ore reserves at these places. (e) The mining area in the south of Chhindwara district had an output of 87,000 tons in 1914, but this has steadily fallen. It was 51,000 tons in 1920, when Sitapar, originally one of the most promising mines, closed down. In 1924 the production was 32,715 tons and in 1925, 37,109 tons.

(1) *Trans. Min. Geol. Inst. India*, Vol. XX, pt. 4, 1926, p. 369.

Vanadium:

The greater part of the world's output of vanadium is obtained from the patronite deposits of Peru. No workable deposits of vanadium-bearing minerals have so far been discovered in India. It is interesting to note that appreciable percentages of vanadic oxide have been detected in the ash of certain coals and asphalts; also that many titaniferous-magnetites contain vanadium. Dr. P. Bruhl found that the bauxite of Kalahandi contained vanadic oxide. It is thus possible that vanadium may be detected in some of the Indian lignites or other carbonaceous material, or perhaps in the magnetite of Salem. In such matters, discoveries are largely dependent on the completeness of chemical analyses, and we are very deficient in such data.

Silicon:

Lumps of quartz or fragments of quartzite are the materials used in the production of ferro-silicon in the electric furnace. The quality desired in the raw material is indicated in the following analysis⁽¹⁾ of a quartzite:

Silica.....	97.0 to 98.25 per cent
Iron oxide and alumina.....	1.0 to 1.75 per cent
Calcium oxide.....	not to exceed 0.2 per cent
Magnesia.....	not to exceed 0.2 per cent
Phosphorus and arsenic.....	to be <i>nil</i>

Iron oxide is not treated as a serious impurity—in fact it is of no importance—but the presence of phosphorus and arsenic are particularly to be avoided. They form calcium phosphide and calcium arsenide in the electric furnace, substances which are retained in the ferro-silicon; further, owing to the instability of these compounds in the presence of moisture, such poisonous gases as phosphoretted hydrogen and arseniuretted hydrogen are liberated. Apart from the danger from these gases, the ferro-silicon containing phosphide and arsenide of calcium cannot be stored for long, as it crumbles and falls to powder when the impurities become hydrated.

(¹) See "Silica in Canada", by L. Heber Cole; Bulletin No. 555, 1923, Department of Mines, Canada.

*Class III**Aluminium:*

This metal is used only as a purifying agent and is usually added to the molten steel in a granulated condition. Although very large quantities of bauxite occur in India, it is not likely that an aluminium industry will be established in this country for many years to come, so that aluminium will have to be imported. A word of explanation is perhaps necessary to avoid any misunderstanding as to what I have stated above. The world's output of aluminium is at present entirely in the hands of a few great firms, who have reduction works, etc., capable of a very much larger production of metal than is at present in demand in the world's markets. They absolutely control the prices, and would not allow a serious competitor to appear in their markets. Furthermore, India has no overwhelming advantages, such as cheap power, very conveniently located bauxite deposits, or an attractive market which could be easily captured, for anyone to think of erecting the elaborate plant necessary for the production of aluminium in this country from domestic bauxite⁽¹⁾.

Titanium:

Ilmenite and rutile have been observed in various places in India, e.g., Manbazar, Supur, and Salbani in Manbhum, and elsewhere close to the smelting centres. However, there is little doubt that, should large quantities of titanium ore be required for the domestic production of ferro-titanium, the monazite sands of the Travancore coast will constitute the chief source of supply. These sands, while containing about 10 per cent monazite, also average 70 per cent ilmenite, 10 per cent zircon, and the remainder quartz, garnet, etc. All the ilmenite, zircon, etc., have had to be magnetically separated in the concentration of the monazite, and till recently they have been regarded in the nature of impurities; but the ilmenite and zircon have now assumed the rôle of by-products—the ilmenite for use in the preparation of the pigment known

⁽¹⁾ See *The Mining Journal* for October 28th and November 4th, 1922; and particularly *The Mining Magazine* for February, 1922. Also "Bauxite", by Cyril S. Fox; Crosby Lockwood & Son, 1927.

as titanium-white, and the zircon for refractory purposes. The reserves of ilmenite sand may be estimated at many thousands of tons of excellent quality ore.

REFRACTORY MATERIALS

The term 'refractory material'⁽¹⁾, as used in the metallurgical and ceramic industries, includes those fire-resisting substances, both natural and prepared, which have been found suitable for the construction of furnaces, kilns, stoves, melting pots, saggars, etc., which are used in the smelting of ores, refining of metals, making of glass, firing of pottery, etc. In the essential processes of the iron and steel industry alone, upwards of a dozen kinds of furnaces, coke-ovens, hot-stoves, etc., are employed. (See the flow sheet accompanying this paper). The linings of furnaces do not last indefinitely, but require renewal periodically. The better the material, other conditions being equal, the longer is the life of the furnace before repairs become necessary. It is quite impossible to state the average life of the several kinds of furnaces used in the iron and steel industry, or of the associated coking ovens and other plant. It is not too much to say that the annual expenditure on refractory materials is a very large item of the working costs of such works. F. T. Harvard (in his *Refractories and Furnaces*, 1912, pp. 113-141) says that, in America, the life of the lining of a basic open-hearth steel furnace averages 350 heats, *i.e.*, about 18 to 24 weeks. The linings of acid open-hearth furnaces last about three times as long. In basic Bessemer convertors, partial repairs appear to be necessary after 20 to 25 heats, and it has become the practice to employ detachable refractory parts, so that these renewals can be made rapidly. The acid process for steel making is at present in use in India only at the metal and steel factory at Ishapur, so that furnace repairs are those largely common to basic furnaces, *i.e.*, renewals are more frequent⁽²⁾.

(1) Detailed particulars in regard to Indian occurrences of these several substances will be found in La Touche's "Annotated Index of Indian Minerals of Economic Value". Commercial information regarding India's resources of asbestos, bauxite, chromite, magnesite, and mica, will be found in the *Bulletins of Indian Industries and Labour* (Nos. 20, 12, 9, 3, and 15 respectively.)

(2) An acid reverberatory furnace has recently been installed at the Kumardhubi Engineering Works.

The linings of blast furnaces, if the most suitable materials are placed in their correct positions for the furnace, may last several years on continuous working, while with faulty refractory materials frequent repairs may be necessary. Blast furnaces used for the production of ferro-manganese are subject to far severer conditions than are those smelting and making pig iron. In consequence of this, the linings of such furnaces will require repairs more frequently.

Among the more important kinds of refractory materials used in the various branches of the iron and steel industry, the following may be mentioned:

Bauxite	Graphite	Zirconia
Chromite	Magnesite	The ideal refractory
Dolomite	Silica (quartz and	Sillimanite
Fire-clay	gannister)	Cyanite

Bauxite

India possesses very large reserves of bauxite⁽¹⁾. Bauxite bricks, if the raw material has not been previously 'dead burned' at a very high temperature, tend to shrink continuously as long as they are exposed to a high temperature. This defect, which may lead to an unmanageable leakage of molten metal, militates against the use of bauxite in the hearths of melting furnaces. After fusion in the electric furnace, bauxite is greatly improved, having been converted into corundum, but it now requires the use of a special binder for the preparation of bricks, etc. The result of such treatment is a high-grade, but very expensive, refractory material. Normal bauxite bricks, when exposed to intense heat, are also converted into masses of corundum so hard that it is difficult to cut them out of a furnace lining, even with the help of steel chisels. Thus it is seen that thoroughly calcined bauxite, when made into blocks or bricks, may be of great value in resisting the abrasion of a sliding charge of hard ore.

The occurrences of good-quality bauxite nearest to the 'Black Country' of India are those about 8 miles west of Lohardaga, in the Ranchi district. The material occurs on

⁽¹⁾ *Memoirs Geol. Surv. India*, Vol. XLIX, pt. 1, 1923.

the tops of the plateaux and could be quarried and placed in wagons at Lohardaga station at a cost not exceeding Rs. 8 a ton. The range in composition of the bauxite from this area is as follows:

Silica.....	0.16 to 4.28	per cent
Titania.....	13.81 to 9.52	“ “
Alumina.....	52.45 to 57.23	“ “
Ferric oxide.....	8.68 to 3.94	“ “
Magnesia.....	1.28 to 0.34	“ “
Combined water.....	23.94 to 23.00	“ “

Chromite

The principal Indian occurrences of chromite, taken in order of importance, are those of Hindubagh in the Zhob valley of Baluchistan, Kadakola in Mysore, and Kimsi Buru in Singhbhum. The average run of ore which can be used for refractory purposes has a chromic oxide content ranging from 38 per cent to 45 per cent. Much of the Indian chromite assays over 52 per cent chromic oxide. Chrome bricks are employed as a neutral lining for basic-steel furnaces. The quality of chromite used for the manufacture of such bricks in the United States is said to average:

Chromic oxide.....	40	per cent
Ferric oxide.....	15	“ “
Silica.....	8	“ “

An analysis of representative Baluchistan ore gave:

Chromic oxide.....	56	per cent
Ferrous oxide.....	13	“ “
Magnesia.....	15	“ “
Alumina.....	11	“ “
Silica.....	1	“ “

No chrome or chromite bricks appear to have been made in India for the domestic market. Chromite bricks, made by the Tata Iron and Steel Co., were being experimented with two years ago. This enterprising company are manufacturing satisfactory chromite bricks for their own consumption. There are no details available regarding imports of chromite bricks. In any case, the quantity must be very small, and the amount

of chromite required for refractory purposes in steel-making furnaces in India is never likely to be large. The Indian production of chromite in 1922 was 22,777 tons, valued at Rs. 3,61,282; in 1921, it was 34,762 tons, valued at Rs. 5,47,382. That all the chromite must be exported is apparent from the following export returns: in 1921—28,741 tons, valued at Rs. 9,87,565; in 1922—39,333 tons, valued at Rs. 12,85,586.

We have no details as to the possible reserves of chromite in India, but large quantities are said to be available, and new occurrences have recently been opened. The United States import nearly 100,000 tons of chromite yearly from various sources for the manufacture of ferro-chromium, for refractory purposes, and in the production of chemicals. Indian manufacturers have barely touched this valuable resource for domestic manufacturing purposes, and large shipments leave the country annually in the raw state.

Dolomite⁽¹⁾

It has been proved that a large proportion of the Indian marbles or crystalline limestones are really dolomites, or at any rate dolomitic in composition. In some cases, as in the limestones of Gangpur State, there are particular bands which are dolomitic. It is one of these bands which is worked at Panposh by the Tata Iron and Steel Company⁽²⁾. Numerous other occurrences of dolomite are known, but the general abundance of good-quality limestone in India and the comparatively small demand for dolomite, on a strict chemical basis, has resulted in these rocks being left more or less unexamined as regards their purity. In consequence, we do not know the extent of the reserves of dolomite in India, but it is certain that very large supplies are available for all purposes to which dolomite is applied. The question of cost at a given works will require investigation, as also of the quality of the material from various places.

Dolomite has properties somewhat similar to magnesite. It is equally refractory, but the presence of a large percentage of lime makes it much inferior in other respects, mainly because

⁽¹⁾ See also under limestone and dolomite in section on fluxes.

⁽²⁾ Similar bands occur in quarries at Birmitrapur worked by the Bisra Stone Lime Co. in Gangpur State.

it readily slakes in air. It cannot be kept for long after calcination without being injuriously affected by the slaking of its lime content, particularly if the calcination has not been conducted at a sufficiently high temperature. It is largely used for temporary repairs in the hearths of basic furnaces because it sets more quickly than calcined magnesite, besides being much cheaper; but it does not set as solidly as magnesite.

Fire-clays

Pottery works have been in operation at Jabalpur and Raniganj for many years. They are worked by Messrs. Burn & Co., who also have erected up-to-date works near Mugma, in the Raniganj coal-field. In addition to these, there are the Kumardubi fire-clay and silica works of Bird & Co., at Kumardubi; the Reliance fire-brick works of Andrew Yule & Co., at Chanch; the Bengal fire-brick works of Martin & Co., at Kulti; and the Bihar fire-brick works of A. C. Banerjee & Co., at Mugma. Except for the Jabalpur works, all the others are in the Raniganj coal-field and the last five are located in the western end of this field. The reason for this concentration is that the better kinds of fire-clays appear to occur in association with the coal seams of the Barakar stage of strata. The quality of these fire-clays varies considerably, but they have a remarkably low iron content. The following analyses⁽¹⁾ may be taken as typical of (A) a normal fire-clay and (B) a somewhat non-plastic highly refractory clay:

	(A) Patlabari	(B) Gourangdi
Silica.....	53.58	50.48
Alumina.....	30.88	35.06
Ferric oxide.....	0.68	0.64
Calcium oxide.....	0.28	0.33
Magnesia.....	0.22	0.20
Sodium oxide.....	0.25	0.04
Potassium oxide.....	1.15	1.09
Loss on ignition.....	12.98	12.12

(1) Kindly supplied by the Research Department of Bird & Co.

The fire-clays are quarried at numerous places around Nirsha-chhati, Mugma, Patlabari, Jagraj, Sinlibari, etc. Dr. E. Spencer reports that there is an abundance of second and third grade fireclay in India, also that there are some first grade seams, but the quantities in these cannot be described as abundant. It is a curious circumstance that the Barakar coal-measure strata, which are characterized by beds of coarse sandstone, frequently with pebbles, should contain fire-clays, and that the Raniganj stage, with far less conspicuous sandstone horizons, should not have yielded any better clays. I doubt if the Raniganj strata have been seriously examined. In the Jharia coal-field, where the lower Barakar beds consist almost entirely of alternations of coarse pebbly sandstones and thick coal seams, with subordinate grey or carbonaceous shales, it almost seems hopeless to look for fire-clays. As regards the adjacent fields of Giridih, Bokaro, etc., I again doubt if any careful search has been made. In these circumstances, it is premature to make any tentative statement as regards the domestic reserves of fire-clays.

In addition to the bedded fire-clays referred to above, there are valuable occurrences of lithomarge and china-clay in various parts of India. The kaolin deposits of Bagalpur and other places in the vicinity of the Rajmahal hills are known to be of very good quality. Fuller's earth is found under the bauxite mantle at several localities, as at Katni; near Lohardaga; on the Jamira Pat, in Sirguja; at Panhala Fort, in Kolhapur; etc.

In view of this lack of knowledge regarding the occurrence of extensive beds of conveniently located fire-clays, it will not come as a surprise when attention is drawn to the large quantities of imported fire-bricks. During the past three years, these imports have been as follows:

1920.....	2,911,375 bricks, valued at Rs.	7,43,760
1921.....	2,759,837 " " "	11,03,772
1922.....	2,934,252 " " "	9,63,250

I am aware that this attractive domestic market is fully known to the manufacturers of Indian fire-bricks, etc. The subject of searching for good fire-clays is receiving careful

attention by the Geological Survey of India, and it is hoped that occurrences of better qualities of this material will be discovered. At the same time, it should be stated that the available material is not really unattractive. The manufactured goods are of fair quality. The amount of fire-clay available is large, but it is a case of mining it rather than cheaply digging it from the locations where it crops out. So far as I am aware, no serious attention has been given to testing the shales met with in shaft-sinking operations anywhere in the Indian coal-fields. Thus, from all that has been said, it is evident that there is not only considerable scope for investigation but, in my opinion, a fair field and an attractive reward for such an enterprise.

Graphite

In 1916, the Indian production of graphite amounted to 1,318.4 tons; last year (1922) no output was recorded. The imports of graphite in 1922 were 1,721 cwt. of graphite crucibles valued at Rs. 1,29,924, and 7,674 cwt. of clean graphite (for paint, lubricating, etc.), valued at Rs. 1,64,121. This is very significant if we remember that graphite occurs in Travancore, Kalahandi, Patna State, Ajmer-Merwara, and other places in India, and was till recently being worked in the areas named. Dr. Fermor⁽¹⁾ discusses the occurrences of Kalahandi and Patna, and mentions several places where deposits were being worked. It is said that much of the Indian graphite is not suitable for the manufacture of crucibles, as it is not of the right quality. It is admitted that most of the graphite obtained in India requires purification for some uses, but it is difficult to believe that this is necessary for refractory materials, where perhaps only 30 per cent of the manufactured product consists of graphite. So far as can be ascertained, no attempts have been made in India to establish the domestic manufacture of graphite crucibles, etc. In this connection, a very useful pamphlet, 'Mining and Preparing Domestic Graphite for Crucible Use,' by G. D. Dub and F. G. Moses⁽²⁾, may be consulted. Attention is also called to the possible treatment

⁽¹⁾ Records, Geol. Surv. India, Vol. LIII, pt. 3, pp. 269-271.

⁽²⁾ U.S. Bureau of Mines, Bulletin No. 112.

of very impure graphite deposits, and the production therefrom of pure graphite by means of the osmosis machine⁽¹⁾. The Indian graphite industry appears to have fallen on evil days simply because the mineral cannot be placed on foreign markets at a price and quality equal to the Ceylon and Madagascar material; but this does not mean that the Indian graphite could not hold its own in a home market if the material were properly prepared and efficiently manufactured for the domestic market.

Magnesite

India possesses really valuable and extensive deposits of magnesite in the Chalk hills of Salem, in Madras. There are other occurrences in Mysore, Baluchistan, Rajputana, and elsewhere which have also been worked. The Kumardhubi fire-clay works at one time manufactured magnesite bricks from magnesite obtained in Mysore State, but this production appears to have been discontinued. Practically all the Indian output of magnesite, whether crude, burned, or dead burned, is now exported to America. The production, chiefly from the Salem area, in 1922 was no less than 19,273 tons, valued at Rs. 2,40,692. The reserves in that region alone may be considered as almost unlimited. Previous to the war, the United States produced roughly 10,000 tons of magnesite annually, while they imported nearly 180,000 tons. In consequence of their inability to import magnesite during the war, it became necessary for them to exploit their domestic deposits. The activity with which this was done is shown in the production of 1918, when 200,000 tons of magnesite were obtained from domestic sources. It is said that roughly 6 lb. of magnesite are consumed for every ton of steel produced by the basic open-hearth process, and that nearly all the magnesite consumed in the United States is utilized in steel making (for refractory purposes). If this is correct, some idea will be gained of the future prospects of the Indian magnesite industry for the domestic demand, should the steel output of this country develop on a scale proportionate to the iron resources of India.

⁽¹⁾ The Mining Journal of June 23rd, 1923, page 478.

Silica

Massive reefs of quartz, or beds of excellent white sandstone or quartzite, are to be found in almost every province in India. The Kumardhubi Works supply 90 per cent of the domestic output for high-class silica bricks. They use a uniform, medium to fine grained, quartzite from Chota Pahari hill, near Bihar Sherif station (E.I.Ry.) in the vicinity of the Rajgir hills in the Gaya district. This source of supply has proved very satisfactory. It is to be remembered that there are other equally valuable occurrences of very pure quartz rock and



Figure 4.—The Silica Brick works of Messrs. Burn & Co. at the potteries, Raniganj.

(Photograph kindly supplied by Mr. W. Bates)

quartzite, *e.g.*, the beautiful saccharoidal quartzite of the Kharakpur hills of Monghyr, which is used by the Raniganj pottery works at Raniganj for the preparation of silica brick. The quartzite is obtained from the neighbourhood of the well-known hot-springs of Sitakund. An analysis of this rock gave 96.86 per cent silica, 1.26 per cent alumina, 0.14 per cent ferric oxide, 0.38 per cent lime, 0.13 per cent magnesia,

0.14 per cent alkalis, and 0.96 per cent loss, etc. The silica bricks are not quite the same as those (with 98 per cent silica) made at the Kumardubi works. They contain nearly 25 per cent of high-grade fire-clay, and have also proved excellent for coke-ovens run with Jharia good-quality coking coals.

In addition to these valuable quartzites, there are others, a little more distant perhaps. The Vindhyan quartzite near Naini (Allahabad vicinity) has been crushed and found pure enough for the manufacture of glass. The crushing of the raw material naturally increases the cost of the product, but a considerable advantage might be derived by passing the comminuted material over sieves and thus grading it. By so doing, the finest dust would possibly find a market as an ingredient for certain pigments; other grades would be suitable for glass sand, or in demand as moulding sands of different qualities; and the coarse and certain fine sizes would be utilized in the manufacture of silica brick, etc.

The supplies of quartz and quartzite within a reasonable distance of the Damuda coalfields are very large, and, as hinted previously, similar reserves of quartz and quartzite will be procurable in other industrial areas. Quartz sands of fair quality are also to be found, but their occurrence is restricted to certain areas. Sands of great purity, and consisting almost entirely of quartz, have been located in the Rajmahal hills, near Colgong; material which is somewhat poorer, but quite suitable for foundry moulds, occurs at Magra, in the Burdwan district; the sands in the Damuda river would, in the absence of purer material, be suitable after grading for foundry purposes, but this material carries appreciable percentages of alumina and ferric oxide and would, therefore, be too readily fusible for use in the manufacture of silica brick, etc. The specifications of sand or quartzite to be used for the manufacture of silica brick call for a content of upwards of 98 per cent silica, with less than 2 per cent ferric oxide, and less than 0.5 per cent alkalis. In this connection, attention is called to the pamphlet "A Comparison of British and American Foundry Practice, with special reference to the use of Refractory Sands", by P. G. H. Boswell, 1922.

Zirconia

Zirconia is normally prepared from the natural oxides of zirconium, i.e., the minerals zirkite and baddeleyite, which occur in workable deposits in Brazil. Crucibles made of zirconia are capable of withstanding very high temperatures, and, owing to the exceedingly small coefficient of thermal expansion, articles made of prepared zirconia can be heated up to $1,000^{\circ}\text{C}$. and then plunged into cold water without, so it is said, being seriously damaged. The only commercial deposits of zirconium-bearing minerals in India are the monazite sands of Travancore. It has been ascertained that roughly 10 per cent of these sands consist of grains of the mineral zircon (the silicate of zirconium). This zircon is obtained as by-product, normally of little value, and would be available at a low price. The preparation of zirconia from the silicate (zircon) is said to be simple and not very expensive, and has been frequently carried out when the raw material was cheaply procured. However, zirconia refractories will only be used in furnaces which are worked at a particularly high and fluctuating temperature. The workable sands of the Travancore coast have been estimated at many hundreds of thousands of tons, so that the supply of zircon for the lining of electric steel furnaces and for other domestic purposes may be considered ample for a long time.

The Ideal Refractory

The inconvenience arising from the use of the many kinds of refractory materials which are required to meet the various conditions prevailing in different kinds of furnaces, has led to the desire to find a single substance which would remain undamaged when exposed for long periods (1) to high temperatures or great variations of temperature; (2) to the abrasive action of a sliding charge of hard ore (such as occurs in rotary roasting furnaces); (3) to the erosion caused by the impinging action of a powerful flame (the roof of an open-hearth reverberatory furnace); (4) to the scour effect of hot, dust-laden flue gases (as in the chequer work of regenerative furnaces); and (5) to the corrosion due to the solvent action of

molten metals and slags (such as takes place in the hearth of a blast furnace.) The specifications of this desired ideal refractory for general purposes have been stated as follows:

- (a) It should be capable of standing indefinitely, without softening, temperatures of from 1,450°C. to 1,750°C.
- (b) It should carry without deformation a load of 20 to 30 pounds per square inch, when forming part of a furnace in operation.
- (c) The coefficient of thermal expansion should be less than 0.000002 (linear)—that of beryl being 0.000001.
- (d) The hardness should not be less than 7 (roughly that of quartz) even when exposed to high temperature under working conditions.
- (e) It should have a neutral chemical reaction so as to remain unaffected when in contact with acid or basic molten slags.

Sillimanite

From theoretical considerations and the results of experimental work in Europe and America, it has been concluded that the substance which would most nearly fulfill the specifications of an ideal refractory will have the composition of an aluminium silicate in the crystalline form known as sillimanite. "This mineral has a definite melting point about 1,830 degrees centigrade, and does not soften below this temperature: its coefficient of cubical expansion is exceedingly small; it is a chemical compound of great stability, and, being neutral in composition, is practically immune to the attacks of acid or basic substances at all temperatures below its melting point. The massive material, sillimanite, is one of the strongest and toughest minerals known. It is not surprising that, owing to the non-discovery of workable occurrences of natural sillimanite, except in the Khasia hills of Assam, attempts have been made to prepare sillimanite synthetically"⁽¹⁾.

⁽¹⁾ With regard to synthetically prepared sillimanite, see papers by A. Malinovsky in the Journal American Ceramic Society, Vol. 3, 1920, p. 40, and a more valuable contribution by A. F. Greaves-Walker in the Transactions of the Jour. Soc. of Chem. Ind., Vol. 41, No. 2, Jan. 31st, 1922, p. 13 T. In this connection it may be stated that occurrences of fibrolite (sillimanite) have been recently discovered in the Khasia hills of Assam. (See Records, Geol. Surv. India, Vol. LV, 1923, Pt. 1, pp. 26-27).

Also see the Mining Journal for March 10th, 1923, p. 195.

Cyanite

Deposits of cyanite (disthene), a mineral having the same chemical composition as sillimanite but with different physical properties, have long been known in the Manbhum district, in the vicinity of Salbani⁽¹⁾. Cyanite and cyanite-quartz-granulite have been found in large quantities in various places in the Dalbhum district. Very little work has been done on these deposits, but they appear to be attractive. The samples of cyanite from Lopsu hill in Kharsawan State and neighbouring areas in Singhbhum which have been sent to England for testing are reported to have given very satisfactory results for refractory purposes, but the material is said to be still under investigation. Cyanite has a specific gravity of 3.6 and a hardness of 7, as against 3.2 and 6.5 to 7 in the case of sillimanite. It is known to have an appreciable thermal expansion. It is reported that cyanite can be paramorphosed⁽²⁾ into sillimanite if exposed to a temperature of 1,320° to 1,380°C. for some time. Such a change is comparable to that of quartz into tridymite, and the alteration in density must result in a considerable expansion in volume—an effect which may prove very useful when cyanite is mixed with fire-clay, as it will largely counteract the shrinkage of the clay. Broken fire-bricks are often crushed and ground to 'grog' and mixed with fire-clay in the manufacture of furnace fire-bricks or blocks, so that the suggestion is not new. However, the 'grog' reduces the shrinkage of the clay, whereas the cyanite would neutralize it. The cyanite-granulite of Dalbhum, if mixed with calcined bauxite, would not only compensate the shrinkage of the latter, but after 'firing' the tendency would be for the whole to so interact as to produce sillimanite.

From all that has been said with regard to refractory materials for the iron and steel industry, it should be assumed that the Indian resources of these materials are quite sufficient to meet any considerable expansion of the domestic metallurgical and ceramic industries. At the present time, the raw

(1) See La Touche's Bibliography on Indian Economic Minerals, Kyanite, discovery by Dr. H. Warth.

(2) See "Data of Geo-chemistry", by F. W. Clarke; U.S. Geol. Surv., Bull. No. 330, 1908, pp. 343-344.

materials of the country are either being largely exported or are not being developed to any appreciable extent. Much remains to be done to encourage the exploitation of these raw materials for domestic consumption.

SUBSIDIARY MINERALS

In the preceding sections of this paper, I have endeavoured to disclose, as far as available information allows, the Indian resources of those minerals which are essential as raw materials for a self-supporting domestic steel industry. To complete this review so as to include those affiliated industries which are dependent on the availability of fabricated iron and steel I have thought fit to include the minerals

Tin ore (cassiterite)

Zinc ore (zinc blende or sphalerite)

Sulphur and iron pyrite.

It is on these substances that the manufacture of tinplate galvanized-iron and sulphuric acid depends.

Cassiterite

Although cassiterite, or tinstone, has been found at Chappatand, Nurunga, Pihra, and near Domchanch in the Hazaribagh district of Bihar, these occurrences have not proved to be of any economic value. Practically all the tin and tin-ore which is exported from British India is obtained from Burma. The more important deposits are situated in the Bawlake State (the Mawchi mines) of Karenni, and in the Amherst, Thaton, Tavoy, and Mergui districts. Alluvial workings are widely distributed in the Mergui district, the best known centre being Karathuri, on the coast, and Thabawleik, on the Little Tenasserim river. Mining methods are primitive and the output is small.

“Other localities are situated on the Lenya and Pakchan rivers, and near Kazat, Kyumon, Palaw, and Palauk. Geological conditions in Tavoy are much the same as in Mergui, but here wolfram has been the more important mineral. The most noteworthy centres are

Mermyingyi, Taungpila, Myekhaubaw, and Kaubauk, where vein and alluvial mining is carried on. At Thaungthonlon, on the Hinduchaung, the Indo-Burma Tin Corporation operates on alluvial deposits with suction and bucket dredgers. The insistence by the Geological Survey officers that other river gravels of the district are worth systematically testing for cassiterite has led several firms recently to take up areas for this purpose. In the Amherst district, alluvial cassiterite occurs around Sakangi, near Paya and Hlutsha, on Belugyun island, and elsewhere. The two tin concessions of the Thaton district are at the extreme ends of the long ridge running parallel to the railway from Pegu to Martaban.... At Mawchi, in Karenni, at least ten important veins are mined.... A certain amount of crude metallic tin is produced in the Mergui district by Chinese methods "(1).

The production of tin ore (concentrates) will be found in the Table given in the *Introduction* of this paper. It will be there seen that, in spite of the fact that the prices of tin and tin-ore have seriously fallen since the boom period of the war, the production from Lower Burma has steadily increased. No estimates of ore reserves can be made, but from the present operations it may be assumed that this industry has an attractive future before it, particularly if the ore could all be smelted locally and the resulting block-tin utilized in India.

Sphalerite

Interesting occurrences of zinc-bearing minerals, chiefly zinc blende (sphalerite, ZnS), have been noted in the lead mines of Jawar, in Udaipur (Rajputana); in the antimonite (stibnite) veins of Shigri, in Lahaul (Panjab); in Sikhim; and in the wolfram-bearing quartz veins of Tavoy (Burma). However, the silver-lead and zinc deposits of the Bawdwin mine, in the Northern Shan States, are the only occurrences which need concern us. In the ore zone, which is roughly 8,000 feet long and 400 to 500 feet wide, two particularly

(1) The above extracts are taken from Dr. Coggin Brown's "Notes on Tin" (see Bulletins of Indian Industries and Labour, No. 11, 1921).

rich ore-bodies have been located. The limits of the high-grade ore are, however, not sharply defined, but shade off into ore of poorer quality. The proved ore reserve is estimated at 4 million tons, averaging 25.3 per cent lead, 17.17 per cent zinc, and assaying 23.3 ounces of silver per ton of lead produced. It is thus clear that there are proved zinc ores capable of an out-turn of 680,000 tons of metallic zinc.

At one time it was anticipated that the zinc ore would be taken to Jamshedpur to be smelted—the zinc being intended for the manufacture of galvanized iron and steel products, whilst a recovery of the sulphur as sulphuric acid was also projected. This scheme has evidently been allowed to fall through, and the zinc ore is going the way of all India's rarer minerals. The exports of zinc ore have leaped in the past two years from 1,500 cwt. in 1920 valued at Rs. 3,040 and 80,000 cwt. in 1921 valued at Rs. 3,00,139 to 361,224 cwt. in 1922 valued at Rs. 13,57,571. Most of this material is said to be shipped to Belgium⁽¹⁾.

Sulphur and Iron Pyrite

The largest known occurrence of sulphur in India, and one that is being worked, is the deposit 12 miles southwest of Sanni, in the Kachhi district of Kelat State (Baluchistan). The reserves of sulphur-rock, averaging 28.79 per cent available sulphur, were estimated by Dr. G. De P. Cotter, of the Geological Survey of India, to be 36,000 tons. This conservative estimate works out to 10,000 tons of sulphur.

There are numerous localities where sulphur has been found in small or trifling quantities, but so far as is known the Sanni deposits, and they are small enough, are alone of economic value. Curiously enough, iron pyrite, which is used on a large scale in Europe and America as a sulphur ore is also not available in India in deposits of great extent. Interesting occurrences of pyrite, some of which have been worked in a small way, are known to exist in various parts of India and Burma. One of these, the Kharwa pyrite mine in

⁽¹⁾ See Table of Indian Mineral Production in the Introduction of this paper.

Ajmer, is said to be an attractive deposit, but details of the ore-body and of the probable quantity of material in reserve are not yet available⁽¹⁾.

In the absence of large domestic deposits of sulphur and pyrite of workable quality, it is evident that India must either continue to be a considerable importer of native sulphur for the manufacture of sulphuric acid in this country, or she must make use of the sulphide ores in Burma. At present, the sulphur in the Bawdwin ores is being lost to India, and the copper ores of Singhbhum are smelted without any recovery of their sulphur content. The sulphur dioxide which is evolved in the roasting and smelting of metallic sulphide-ores, such as chalcopyrite, galena, blende, etc., is largely used in Europe and America for the preparation of sulphuric acid. The sulphide ores of Burma and India could easily be smelted in the vicinity of Calcutta, or some point on the Orissa coast, with advantage to the country. Besides establishing a new branch of the metallurgical industry, the undertaking would be of a profitable nature in many ways—economically and politically. The zinc ores of Burma and Bawdwin, and the newly discovered deposit north of He Ho, are of national importance to the Empire, and are being recognized as such in commercial circles.

CONCLUDING REMARKS

I am conscious of having put together a paper which seems to be unduly long. It would have been a reflection on the Indian iron and steel industry to have erred on the side of being too brief. The raw materials are so many and so varied that it takes a paper of some length to put these several substances in their true perspective. I trust that I may be allowed this opportunity of recording my thanks and indebtedness to the metallurgical-chemists, geologists, and managers of the Bengal Iron Co., the Indian Iron and Steel Co., and the Tata Iron and Steel Co. I would acknowledge the assistance given me by the managers of the various coke-oven plants at Giridih, Kulti, Hirapur, Bararee, Bhowra, and Jamshedpur.

⁽¹⁾ See "Notes on Sulphuric Acid, Sulphur and Iron pyrite", in Bull. Indian Indus. Lab., No. 28, 1922).

I am grateful for much information from the managers of the Kumardubi Fire-Clay and Silica Works and the Raniganj Pottery Works. Finally, I am under a great obligation to colleagues of the Geological Survey of India, in particular to Dr. E. H. Pascoe, the Director, through whose kindness I am permitted to present this paper.

APPENDIX

The Bengal Iron Co., Ltd.

Location:

The works of this company are situated at Kulti, near Barakar, in the Burdwan district of Bengal, on the main (Grand Chord) line of the East Indian railway about 140 miles from Calcutta.

The present works at Kulti originally started, in 1875, to work the local iron ores of the Ironstone stage of the Damuda series. The works were closed in 1879, then worked for 8½ years, and were finally purchased by the present company (then known as the Bengal Iron and Steel Co., Ltd.) in 1889. Since that date the whole plant has been re-modelled, and in 1919 The Bengal Iron Co., Ltd., was registered with an authorized capital of £2,500,000.

Raw Materials:

This company owns collieries in the Jharia and Raniganj coal-fields, but also obtains supplies of coal from other collieries in both these fields. The coal used for coke making is a blend of several coals, including No. 17 seam Noonoodih in Jharia, Ramnagar in the Raniganj field, and others.

Their supplies of limestone are obtained from the Bilaspur district in the Central Provinces. They possess a dolomite property at Semra, in the Palamau district of Bihar and Orissa.

They obtain their iron ore, a high-grade hematite, from their own property near Manharpur, in the Kolhan estate of the Singhbhum district.

The blast-furnace charge has a rough proportion of 21 cwt. coke, 31.5 cwt. iron ore, 40 lb. manganese ore and scrap, and 13.75 cwt. limestone per ton of pig iron produced. A

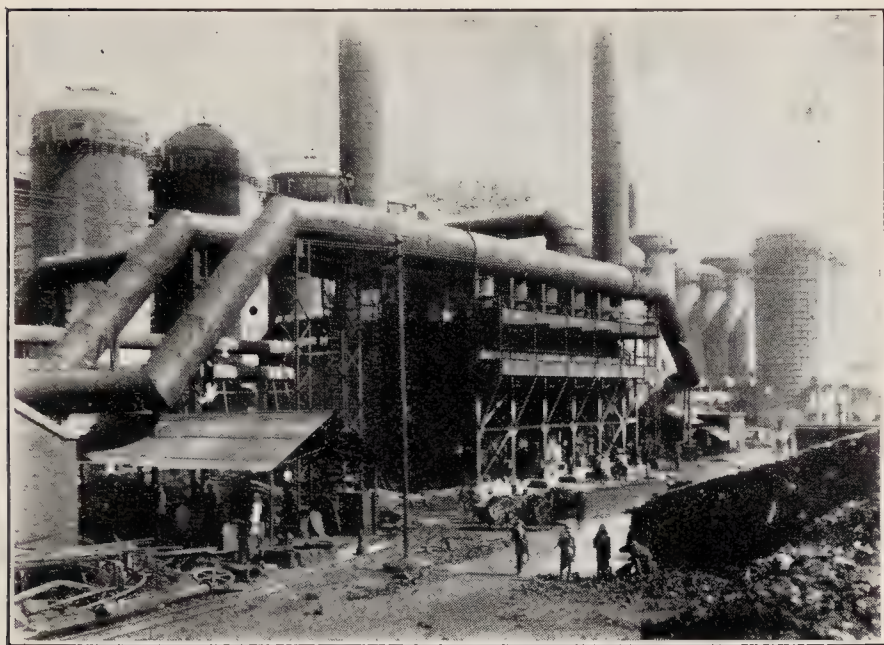


Figure 5.—The works of the Bengal Iron Co., Ltd., at Kulti, on the East Indian Railway. These works have recently been carefully modernized.

(Photograph kindly supplied by Mr. A. Dawes Robinson)

typical coke which is sometimes used has the following analysis: moisture 0.40 per cent, ash 18.0 per cent, volatile matter 0.4 per cent, fixed carbon 80.82 per cent, sulphur 0.78 per cent, and 0.46 per cent of phosphoric acid in the ash.

Products and Plant:

The coking plant consists of four batteries of Simon Carves by-product regenerated ovens, with 34 ovens in each. When all four batteries are functioning, it is expected that an output of 200,000 tons of coke will be made annually. At present only two batteries are at work, and a third is in repair. The output capacity is roughly 900 tons of coke a day. The waste heat from the ovens passes to a battery of boilers, where it is used for raising steam for the electric generating plant, which has a capacity of 2,500 kilowatts.

The furnace plant comprises five blast furnaces, of which Nos. 4 and 5 are mechanically charged. No. 5 has been provided with a Brown Hoisting Co.'s charging apparatus. With the developments now in hand, the furnace plant will have a capacity of 250,000 tons of pig iron per annum.



Figure 6.—Coke Ovens at the works of the Bengal Iron Co., Ltd., at Kulti.

(Photograph kindly supplied by Mr. A. Dawes Robinson)

The foundries have been extended and now comprise two pipe foundries, one general foundry, and two sleeper shops, with an out-turn of 100,000 tons of finished castings per annum.

The water supply for the Kulti works is obtained from the Barakar river, 2 miles away. The pumping station is situated in the Manberia mouza, due north of Barakar station and close to the East Indian Railway Company's pumping station. Improvements are being instituted which will insure a supply of 60,000 gallons of water per hour for all purposes.

The managing agents of the Bengal Iron Company are Messrs. Martin & Co., of 6 and 7 Clive Street, Calcutta. This firm have now taken over the various interests of Messrs. Burn & Co., and consequently influence the commercial activities of the Indian Iron and Steel Co., Ltd. The combination of the production of the Bengal Iron Co., Ltd., with the output of the Indian Iron and Steel Co., Ltd., will be a very important feature of the iron industry of India in the near future.

*The Tata Iron and Steel Co., Ltd.**Location:*

The works of this company are situated at Jamshedpur (formerly the town of Sakchi) in the Singhbhum district, Bihar and Orissa, being connected by a 3-mile branch line, owned by the company, to the Bengal Nagpur Railway Company's main Bombay-Calcutta line at Tatanagar (earlier known as Kalimati) station. This station is 156 miles from Calcutta and 1,067 miles from Bombay. All the supplies for the manufacture of iron and steel at Jamshedpur are received at Tatanagar.

The project was taken in hand in 1907, when the Tata Iron and Steel Co., Ltd., was formed with a capital of Rs. 2,31,75,000 (£1,545,000). The site at that time was a typical Indian jungle. The reasons for selecting this site were, firstly, a plentiful supply of water from the Subarnurekha river and, secondly, because it is central to sources of material and to Calcutta. By 1911, the plant had been erected with its coke ovens, blast furnaces, steel furnaces, and rolling mills, ready to manufacture and compete in the iron and steel industry.

Raw Materials:

The company's requirements of coal are obtained from the Jharia and Raniganj coal-fields—partly from their own properties and partly from other collieries—situated from 110 to 120 miles to the north of Tatanagar. The company's properties are estimated to contain enough coal to supply their requirements for over 100 years, but they deem it advisable to purchase some coal from other collieries. Out of the 21,176,600 tons of coal produced in India in 1924, this company consumed 1,475,585 tons, of which 4,88,948 tons came from their own collieries.

Their supplies of iron ore are obtained from Gorumahisani, Sulaipat and Badampahar in the Mayurbhanj State, and from Noamundi in the Kolhan estate in the Singhbhum district, at distances of 40, 49, 56, and 80 miles, respectively, from Tatanagar. The total Indian production of iron ore in 1924 was 1,445,313 tons, of which the Tata company produced 902,404 tons, or about 62 per cent.



Figure 7.—The Gorumahisani Iron-ore Mines of the Tata Iron and Steel Company.

(Photograph kindly supplied by the Tata Iron and Steel Co., per favour of Mr. F. G. Percival)

Supplies of limestone and dolomite are largely obtained from Gangpur State, about 106 to 120 miles west of Tatanagar. Small quantities of limestone are drawn from Sakti State, and also from the Bilaspur district in the Central Provinces, 250 miles west of Tatanagar. Supplies are also obtained from Katni, in the Jabalpur district of the Central Provinces. The total Indian production of limestone and dolomite in 1924 was 1,851,455 tons, of which 439,977 tons were absorbed at Jamshedpur, largely for flux but also for building purposes.

Manganese ore is obtained from the Central Provinces at a distance of roughly 500 miles from Tatanagar. Chromite is supplied from near Chaibassa, in the Singhbhum district, 50 miles from Tatanagar. Supplies of magnesite come from Kadakola, in Mysore State, 1,329 miles distant.

Coke is produced from 50 Koppers patent regenerative ovens, with recovery plant; and 150 Wilputte coke-ovens, in 3 batteries of 50 ovens each.

Products:

The Wilputte ovens are equipped with up-to-date labour-saving appliances, including coal handling machinery, belt conveyors, quenching cars, modern coke wharf, loading bunkers, etc. The whole output of coke is used at the blast furnaces and for general purposes at the works. An average analysis of the coke is: moisture 2.62 per cent, ash 23.26 per cent, volatile matter 2.04 per cent, fixed carbon 74.51 per cent, sulphur 0.58 per cent, phosphorus in ash 0.81 per cent, and phosphorus in coke 0.188 per cent. An average analysis of the sulphate of ammonia (for neutral and dry material) is: moisture 0.054 per cent, acidity 0.004 per cent, ammonia 25.73 per cent, ammonium sulphate 99.81 per cent, and nitrogen 21.16 per cent. An average analysis of the coal-tar (thin tar) is: ammoniacal liquor (120°C. to 140°C.) 1.50 per cent, light oils (140°C. to 170°C.) 2.23 per cent, carbolic oils (170°C. to 230°C.) 9.83 per cent, creosote oils (230°C. to 270°C.) 4.38

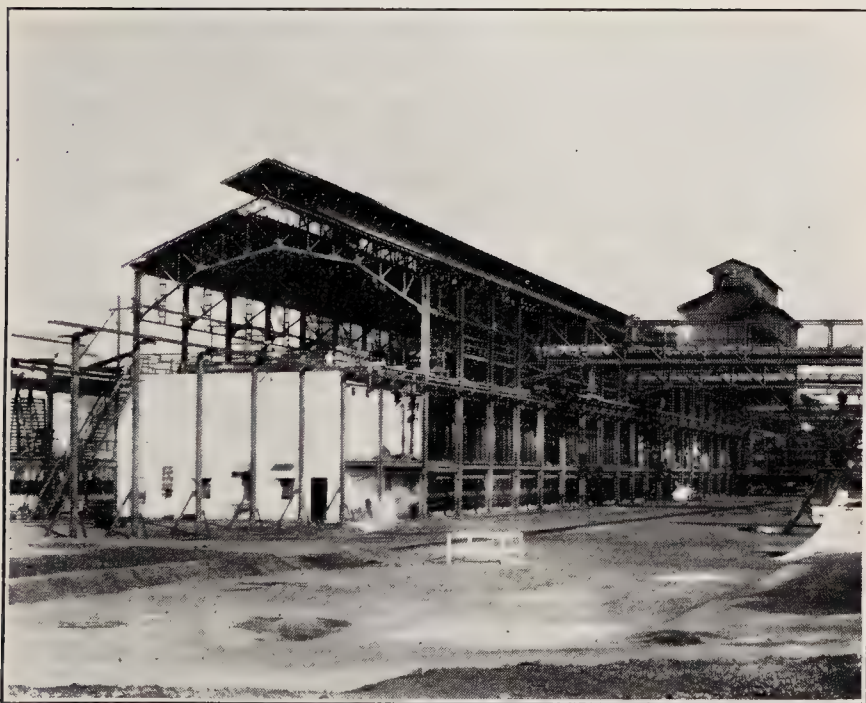


Figure 8.—Wilputte Coke Ovens at the Tata Iron and Steel Co.'s works at Jamshedpur.

(Photograph kindly supplied by the Tata Iron and Steel Co., per favour of Mr. F. G. Percival)

per cent, anthracene oils (270°C. to 350°C.) 22.73 per cent, naphthalene 10.41 per cent, pitch 46.36 per cent, and loss on distillation 2.56 per cent.

Pig iron is prepared in five blast furnaces, three of 300 tons capacity, and two of 500 tons capacity. The latter are of recent design and are equipped with electrically-driven skip hoists, gas washers, and other modern improvements. The grades and analyses of the pig iron produced are as follows:

Furnace	Silicon	Manganese	Phosphorus	Sulphur
No. 1.....	2.51 and over	1.00 to 1.50	0.35 to 0.40	0.025
No. 2.....	2.01 to 2.50	"	"	0.03 to 0.05
No. 3.....	1.51 to 2.00	"	"	0.035 to 0.05
No. 4.....	1.01 to 1.50	"	"	under 0.04
Basic.....	under 1.00	"	"	under 0.04

Part of the iron is taken direct from the furnaces in a molten condition for steel making, part is run into beds at the furnace for sand-cast pig iron, and part is poured into the pig-casting machine. The exports of pig iron from India during 1924-25 were 341,326 tons, of which the Tata company shipped 133,242 tons, *i.e.*, 39 per cent of the export total.

Steel (West Plant) is manufactured from seven open-hearth furnaces—four of 50-55 tons capacity and three of 60-65 tons capacity—molten iron being stored in a mixer of 300 tons capacity. The following grades and analyses of steel are produced:

	Carbon	Manganese	Sulphur	Phosphorus
Rails, 60 to 100 lb.....	0.55 to 0.65	0.60 to 0.90	0.05	0.05
" 44½ to 50 lb.....	0.50 to 0.65	0.60 to 0.90	0.05	0.05

Low-carbon mild steel is produced with carbon ranging from 0.08 to 0.35 per cent, manganese 0.40 to 0.70 per cent, and sulphur and phosphorus each under 0.05 per cent. Special

steels are also manufactured, containing from 0.08 to 1.00 per cent carbon, 0.30 to 0.80 per cent manganese, and sulphur and phosphorus under 0.05 per cent.

The steel is poured into ingot moulds, and the ingots, after being re-heated in the soaking pits, are taken to the mills, where a 40-inch steam-driven blooming mill converts them into blooms. The blooms are transferred to the re-heating furnaces and, when re-heated, are rolled into either rails or structural sections on a 28-inch mill, passing through a set of roughing, intermediate, and finishing rolls.

Steel (East Plant) is produced in a duplex plant. The molten iron is partly blown in two Bessemer converters of 20–25 tons capacity before being transferred to two 200-ton open-hearth tilting furnaces. A mixer of 1,300 tons capacity stores and keeps the molten iron ready for use. One 40-inch reversing blooming mill rolls blooms for rails, sleepers, sheet and tin bars. One combination rail and structural mill is capable of rolling all sizes of rails from 30 lb. to 100 lb., and when additional equipment is installed, will handle beams up to 24 in. by 7½ in., channels up to 15 in. by 4 in., angles up to 8 in. by 8 in. In addition, there are one continuous-sheet bar and billet mill; one merchant mill, with an auxiliary finishing mill; and a 30-inch sheet mill, comprising four hot mills, nine finishing mills, and two cold mills.

The works which belonged formerly to the Agricultural Implements Co. are now a department of the Tata Iron and Steel Co., Ltd., and the old name is consequently largely a misnomer, although the trade mark, 'Agrico', is retained.

The Indian Iron and Steel Co., Ltd.

Location:

The works of this company are situated at Hirapur, about 3 miles from Asansol, Burdwan district, Bengal, in the fork made by the Bengal Nagpur railway and the main line of the East Indian railway at their junction at Asansol, 132 miles northwest of Calcutta. The works are connected with the Bengal Nagpur railway at Burnpur station, and with the East Indian railway at Borachuck station. The Indian Iron

and Steel Co., Ltd., was registered in 1918 with an authorized capital of Rs. 3,00,00,000, subsequently increased to Rs. 3,01,50,000 (£2,010,000). The works were completed in 1922 and have been placing pig iron on the market since 1923.



Figure 9.—The Blast Furnaces of the Indian Iron and Steel Co., Ltd., at Hirapur, near Asansol.

(Photograph kindly supplied by Messrs. Burn & Co. of Calcutta)

Raw Materials:

This company's coal properties are in the Jharia coal-field, and contain large reserves in an area of 900 acres. Their supplies are obtained both from their own property and from various other collieries. The coal used in the coke ovens is a mixture or blend from several seams.

The coke-oven and by-product plant comprises two batteries, each of 80 Simon Carves horizontal-flue waste-heat ovens. These are capable of producing 1,000 tons of coke a day, and provide all the coke at present necessary. The ovens are filled by electrically-driven coal charging cars. Combined leveller and coke rams, also electrically driven, are provided for levelling the charge and for discharging the

coke. The hot coke is discharged on to inclined-bottom coke cars, which are hauled by electric locomotives to quenching stations adjoining the ovens. The quenched coke is discharged from the cars on to a short inclined coke bench, from which a belt conveyer takes the coke to the screens. The 'breeze' passes into hoppers, from where it is loaded into wagons—the larger coke drops into the wagons direct and is moved away for use.

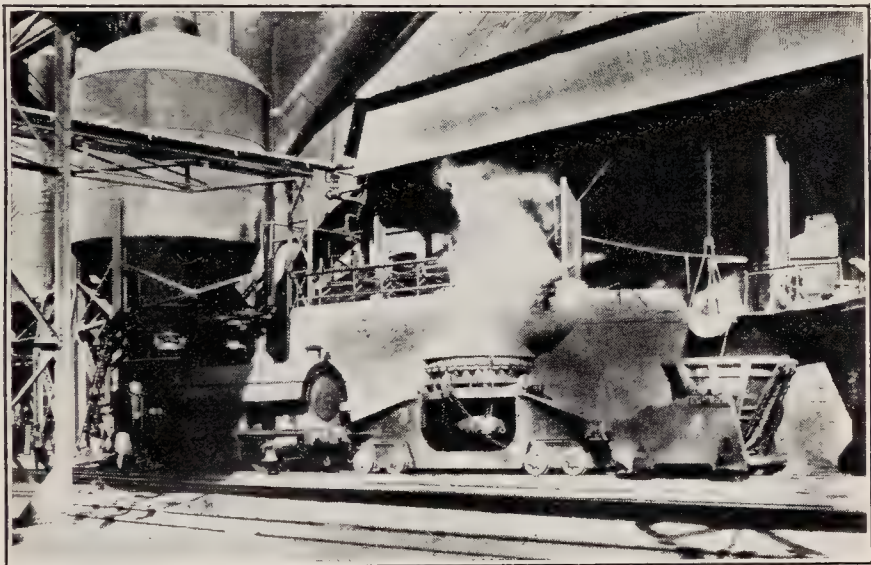


Figure 10.—Tapping off slag at the works of the Indian Iron and Steel Co., Ltd., at Burnpur, near Asansol.

(Photograph kindly supplied by Messrs. Burn & Co. of Calcutta)

The recovery of the by-products—sulphate of ammonia and tar—is effected on the direct recovery system, with serpentine gas-cooling apparatus. The plant is guaranteed to be capable of recovering 99 per cent of the total tar and 98 per cent of the total ammonia (as sulphate of ammonia) in the gas. A sulphuric acid plant, capable of producing 18 tons of 80 per cent acid per day from natural sulphur, is installed. The analysis of the sulphate of ammonia is: ammonium sulphate 97.0 per cent, free sulphuric acid 0.3 per cent, moisture 2.7 per cent, and traces of tarry matter. The coal tar contains: ammonia liquor 2.5 per cent, crude naphtha 1.5 per cent, light oils 10.5 per cent, creosote oils 16.0 per cent, anthracene oil 11.5 per cent, and soft pitch 58.0 per cent.

This company's iron ore comes from Gua, where their leases cover nearly 10 square miles in the Singhbhum district. The mines are connected by a broad-gauge railway to the main line of the Bengal Nagpur railway. An average analysis of the iron ore is said to be: iron 64.0 per cent, phosphorus under 0.06 per cent, sulphur under 0.03 per cent, and manganese 0.05 per cent.

The company's limestone property covers an area of 581 acres at Guttitangar, near Bisra, in the Gangpur State. The quarries are within easy reach of the Bengal Nagpur railway.

Products:

At present, the Indian Iron and Steel Co. operate only two blast furnaces, but provision has been made for the addition ultimately of six more. The two furnaces are of the most modern design, mechanically charged and fitted with revolving distributors. Each has a capacity of 350 tons daily, but this can be increased to 500 tons. Each furnace has a hot-blast stove installation of five two-pass side-combustion-type stoves, 25 feet diameter and 95 feet high, with a dust catcher and two centrifugal dust separators. The tunnel system for handling the ore from the trestle to the skip cars is employed. The entire stock trestle is double tracked to facilitate the handling of raw material. For handling the hot metal from the furnaces, 75-ton-capacity ladles have been provided, and these convey the molten metal to the double strand jug-casting machines or to the sand-cast pig bed, which is equipped with an overhead electric crane and lifting magnet for picking up the pig iron.

Various grades of foundry pig-iron and high-phosphorus pig-iron are produced. The grades of the 'Burn' high-phosphorus pig-iron are as follows:

	Silicon	Manganese	Phosphorus	Sulphur
No. 1.....	2.75 to 3.25	0.60 to 1.0	0.5 to 0.8	0.03
No. 2.....	2.25 to 2.75	"	"	0.035
No. 3.....	1.75 to 2.25	"	"	0.04

Analyses of 'Burn' standard foundry pig-iron are:

	Silicon	Manganese	Phosphorus	Sulphur
No. 1.....	2.75 to 3.25	1.0 to 1.5	0.3 to 0.4	0.03
No. 2.....	2.25 to 2.75	"	"	0.035
No. 3.....	1.75 to 2.25	"	"	0.04
No. 4.....	1.50 to 1.75	"	"	0.05

The necessary circulating water for the turbo-blowers, blast-furnace plant, and general works' requirements, is pumped from a large reservoir at the works, which has a capacity of, roughly, 300,000,000 gallons. The supply for the reservoir is pumped from the Damuda river, $2\frac{1}{2}$ miles away, by two pumps, each capable of delivering 60,000 gallons an hour. The riverside pumping station also supplies 20,000 gallons an hour to the water-works, for the supply of filtered water for the employees and staff.

THE MANUFACTURE OF STEEL IN INDIA BY THE DUPLEX PROCESS

BY B. YANESKE*

(Sydney, N.S., Meeting, September 10th, 1927)

SECTION I. INTRODUCTION

The Duplex process described in this paper is a combination of the Bessemer and open-hearth methods of steel manufacture, and consists of desiliconizing, and partly or almost completely decarburizing, molten pig iron from the blast-furnace in an acid-lined Bessemer converter, and subsequently dephosphorizing the metal in the basic open-hearth furnace. This process is practised successfully in India by The Tata Iron and Steel Company under difficult climatic conditions with more than 99 per cent of native labour, and the present paper consists of a description of the methods adopted by this Company at their works at Jamshedpur.

Although the Duplex process originated in Europe and has been practised in Great Britain and on the Continent, it has never been developed in Europe to the degree it has in America, where it is successfully worked on a very extensive scale at several of the largest steel works; and in large measure the American practice is followed at The Tata Iron and Steel Company's works in India, the Duplex plant of this company being very similar in design to that of the Indiana Steel Company at Gary, U.S.A.

Jamshedpur ⁽¹⁾ was chosen as the site of the works of The Tata Iron and Steel Company on account of its central position with regard to the raw materials required for the manufacture of iron and steel, and also its proximity to the

*Assistant Superintendent, Duplex Plant, The Tata Iron and Steel Company, Limited, Jamshedpur, India; late of Sheffield, England.

⁽¹⁾ Jamshedpur was originally named Sakchi. The name was changed on January 2nd, 1919, when the then Viceroy of India, Lord Chelmsford, visited the Tata Iron and Steel Works and announced Jamshedpur as the new name for Sakchi to perpetuate the memory of the distinguished founder of the Company, the late Mr. Jamshedji Nusserwanji Tata.

junction, about $2\frac{1}{2}$ miles from the town, of two rivers, the Khorkai and the Subarnarekha, the latter of which supplies the water for the works and municipality. The town, which occupies an area of 25 square miles, is situated in the Singhbhum district of the Province of Bihar and Orissa, Bengal, and is $2\frac{1}{2}$ miles north of the wayside station of Tatanagar ⁽¹⁾ on the main line of the Bengal-Nagpur railway. Coal is found to the north, iron-ore to the south, and dolomite and limestone to the west, while the port of Calcutta, about 150 miles eastward, renders convenient the import and export of materials.

SECTION II. THE DEVELOPMENT OF THE TATA IRON & STEEL WORKS ⁽²⁾

(a) 1908 to 1916

The Tata Iron & Steel Company is of comparatively recent growth, and although the idea of creating such a manufacturing concern was formulated by the late Mr. Jamshedji N. Tata (Born March 3rd, 1839; died May 19th, 1904) during the latter years of his life, it was not until February 27th, 1908, or nearly four years after his death, that a definite start was made on the erection of the works, when the first stake for marking out the foundations was driven on a plateau 536 feet above sea-level in the midst of a very large jungle which had to be cut away as the works were extended. Today the plant is one of the largest iron and steel works on one site in the British Empire, and a brief history of its development may be of interest.

The actual construction was begun in the autumn of 1908. The first iron (from 'A' blast furnace) was made on December 2nd, 1911, while on September 22nd, 1912, the second ('B') blast

⁽¹⁾ Tatanagar was originally named Kalimati, but the name was changed by the Government of Bihar and Orissa shortly after the name of Sakchi was altered to Jamshedpur.

⁽²⁾ The early stages of the development and practice of the Tata works have been previously referred to by the following:

A. Bose, Jour. Iron and Steel Inst., 1914, No. I, p. 528;
H. M. S. Tuckwell, Jour. Roy. Soc. Arts, 1918, No. 66, p. 189;
A. McWilliam, Jour. Iron and Steel Inst., 1918, No. I, p. 451; and
C. P. Perin, Am. Iron and Steel Inst., October 22nd, 1920;

while papers on more recent practice have been presented by:

J. L. Keenan, Jour. Iron and Steel Inst., 1925, No. II, p. 45; and
R. Mather, Proc. Sheffield Soc. Eng. and Met., 1926, Part I, p. 35.

furnace was blown-in. The first heat was tapped from the open-hearth furnaces on February 16th, 1912, and in this month the first rails were rolled.

The plant as erected up to this period was designed for an estimated annual output of 180,000 tons of coke, 160,000 tons of pig iron, and 100,000 tons of steel (70,000 tons of rails, beams, and shapes; 20,000 tons of bars, hoops, and rods; and 10,000 tons miscellaneous). The works at this time consisted of 180 Coppée non-recovery retort coke-ovens (two batteries of 90 ovens each); two blast furnaces, 'A' and 'B', each 77 feet in height with 12-foot-diameter hearths and 19-foot-diameter bushes, and each of 175 tons daily capacity for casting iron either into ladles for the open-hearth steel furnaces, or into pigs for sale or foundry use; one 300-ton hot metal mixer; and four 40-ton stationary open-hearth steel furnaces for converting the pig iron into steel in the form of ingots. The old plant included 16 Morgan mechanical gas-producers with revolving bottoms, hearths, and tuyeres; three 4-hole gas-fired soaking pits; one 40-in. two-high reversing blooming mill, capable of rolling annually about 200,000 tons of cast-steel ingots into blooms and billets; one 28-in. reversing mill with three stands of two-high rolls provided with travelling tables, for rolling blooms into rails and structural shapes and capable of producing annually about 100,000 tons of medium and heavy rails, and medium sections up to 15-in. by 6-in. beams; and a bar mill consisting of one 16-in. and one 10-in. mill for rolling billets into bar products (including round, square, and flat bars, fish-plate bars, and bearing-plate bars) and light structural shapes and rails, etc. The joint capacity of the latter two mills together with that of a second 10-in. mill subsequently added and referred to later in the paper, is about 40,000 tons of finished products per annum. All these older mills are steam-driven.

Power for operating the plant was furnished from a central station containing three Escher-Wyss turbo-blowers, each of 35,000 cubic feet capacity, for supplying blast to the blast furnaces; three 1,000 k.w. electrical generators and two 500 k.w. motor generator sets for electric power generation and conversion; together with water service pumps for works and town service. All of these units were high pressure, con-

densing, steam-driven, and received steam from a boiler house containing sixteen 500 h.p. Babcock and Wilcox boilers, or a total of 8,000 h.p. Six of the boilers were arranged for burning either coal or blast-furnace gas.

The plant contained an iron-foundry equipped with two cupolas driven by electric rotary blowers, core ovens, brass furnaces, etc.; pattern, machine, and forge shops, blacksmiths' and boiler shops, etc., with the usual equipments suitable for works' maintenance and current repairs; and a water supply pump-house at the Subarnarekha river, containing three Sulzer 4-million-gallon daily capacity pumps.

At this point the river was dammed and a cooling reservoir constructed within the works to ensure an adequate supply of water at all seasons. This reservoir was capable of impounding 241 million gallons of water. Two filter beds were provided for supplying water to the boilers and the town.

For the movement of material to and from the plant, an inter-works railway system was built connecting with the shunting yard of the Bengal Nagpur railway at Tatanagar.

In order to secure the supply of raw materials needed, iron-ore leases were developed near Chanda, at Dhullee and Rajhara, and at Gurumahisani; dolomite quarries at Gangpur; and limestone quarries at Jukehi. Colliery purchases in the Bengal coal fields included Bhelatand and Jarma, while later additions to colliery holdings included the purchase of Malkera-Choitadih and Jamadoba.

The plant was improved and extended from time to time, and in July, 1914, the installation of a battery of 50 Koppers coke ovens with by-product recovery plant for the recovery of coal-tar and gas and the manufacture of sulphate of ammonia, was commenced. Pending the completion of these ovens, a battery of 50 Drag ovens was built and later discarded.

In connection with this by-product plant, a Simon-Carves sulphuric acid plant, with a daily capacity of 32 tons of acid, was installed. The coke ovens proper were completed in the beginning of 1916 and the by-product plant a few months later, and the whole plant was put into operation in August, 1916. It was not found feasible at that time to discard the old battery of 180 Coppée non-recovery ovens, but the waste gases from one-quarter of these ovens were afterwards utilized to operate

a power plant and thus economize in coal; but this old coke plant is now idle.

This addition to the coke plant increased the steam demand, and a second boiler-house was built with 1,000 h.p. of Babcock and Wilcox boilers arranged for burning waste gases from the old Coppée non-recovery ovens. To take care of the additional electrical requirements, a 1,500 k.w Westinghouse turbo-alternator was installed in the power house.

In 1915, a new foundry was specially erected for the manufacture of cast-iron pot sleepers, and commenced operations in September of the same year; but after making the same for the Indian railways for several years, their manufacture has recently been discontinued, and pressed-steel trough sleepers are made instead. In September, 1915, another 10-in. bar mill was put into operation.

About this period the hearths of 'A' and 'B' blast furnaces were enlarged at the time they were out for relining. The four original 40-ton open-hearth furnaces were also enlarged, in 1916, to make 55-ton heats, and two new furnaces of 75 tons capacity were added with additional Morgan gas-producers, these being put into operation in 1917.

(b) 1917 to 1926

Owing to the steadily increasing demand for iron and steel products, the Company launched out on a gigantic scheme of greater extensions to the works in the autumn of 1916, which included the erection of the Duplex plant, consisting of a 1,300-ton hot metal mixer, two 25-ton Bessemer converters, and two tilting open-hearth furnaces of 200-tons and 250-tons capacity, respectively, etc., the operation of which is the main subject of the present paper.

During these extensions 'A' and 'B' blast furnaces were further enlarged so that the bosh diameter of each was 19 ft. 8 in., with a hearth diameter of 14 ft. 8 in., and a rated capacity of 315 tons of basic pig iron per day. Three more blast furnaces were erected. Two of these ('C' and 'D') are 89 ft. 1 $\frac{7}{8}$ in. in height with bosh diameter of 21 ft. 6 in. and hearth diameter of 17 ft. 0 in., having a rated capacity of 500 tons of pig iron daily, but which is now considerably exceeded, for 'C' furnace is at present producing about 650 tons, and 'D' furnace

about 700 tons, of pig iron per day. These furnaces were designed on the most modern lines, and are further described in Section III of the paper. The third new furnace ('E') was originally erected in Batelle, Alabama. This furnace was purchased in the United States in July, 1917, was dismantled and shipped to India and re-erected at Jamshedpur with the same size of bosh and hearth as 'A' and 'B' furnaces, the height of this furnace being 81 ft. 10½ in.

These additional blast furnaces necessitated additions to the power plant and blowing equipment. No. 1 power house was enlarged by adding 4,500 h.p. of Babcock and Wilcox coal and gas-fired boilers, 2,000 h.p. being installed in 1918 and 2,500 h.p. in 1921. A 5,000 k.w. British Thomson-Houston turbo-generator was installed, and, to make room for the power unit, one of the old 1,000 k.w. Escher-Wyss generators was removed.

On account of the increased size of the blast furnaces 'A' and 'B', the existing blowing equipment was inadequate, and to relieve the blast shortage new air ends of larger size for the Escher-Wyss blowers were fitted, the steam ends being of sufficient capacity, and an Ingersoll-Rand turbo-blower, capable of delivering 37,500 cubic feet of air per minute, was added to supply the air for 'E' blast furnace.

A new boiler plant was constructed containing 20 Wickes boilers equipped with super-heaters, each boiler having a normal rating of 500 h.p. or a total of 10,000 h.p.

A second power house was erected close to the above mentioned boiler plant in order to minimize steam-line losses, and contains the blowing equipment for 'C' and 'D' blast furnaces, consisting of three General Electric 45,000 cu. ft. capacity, and one 37,000 cu. ft. capacity, turbo-blowers.

Included in these greater extensions was the installation of a pig-casting plant consisting of a single two-strand machine for casting molten blast-furnace iron into pigs. This machine is described in Section III of the paper.

Another stationary 75-ton open-hearth furnace with the necessary Morgan gas producers was built, making seven stationary open-hearth furnaces in all.

A new coke plant was installed containing 150 Wilputte coke ovens, arranged in three batteries of 50 ovens, with an annual output of 562,000 tons of coke.

For the economical handling of coal to the coke ovens, a three-track hopper was constructed, over which wagons are shunted and coal dropped through chutes on a system of belt conveyors, which carry the coal to the top of the crusher building. Here the coal passes through a pair of double roll crushers to a shuttle belt conveyor for distribution in two mixing bins. From these bins, the coal is conveyed to either of three hammer mills for pulverizing the coal. From these hammer mills the coal is taken by means of a belt conveyor to the top of a 3,000-ton capacity coal storage bin between coke oven batteries Nos. 2 and 3. From this bin the coal is fed through gates in the bottom of the bin into either of two coal-charging lorries, each capable of taking a charge of $12\frac{3}{4}$ tons of coal, which is sufficient to fill one oven. Two pusher machines are provided for pushing the coke out of the ovens directly into coke quenching cars. These cars are then hauled to either of two quenching stations, where the coke is quenched in the car. After the quenching operation, which occupies about one minute, the car is hauled to either of two coke wharfs where the side of the car is opened by air pressure and the coke automatically slides on the drying wharf and the quenching car proceeds to another oven. The coke wharfs are built on a slope, and, by raising a series of fingers, a portion of the dried coke is allowed to fall on a belt conveyor, which carries the coke to a screening station located over a series of loading tracks. Here the coke is screened and the breeze removed, and each grade automatically dropped into railway wagons for shunting to the blast furnace coke-bins or wherever the product may be required. The coal is scarcely touched by human hands from the moment of its arrival from the Jherria coal-fields to the time when its coke product is shunted to the blast-furnace yard.

In connection with these new ovens, by-product apparatus for the recovery of coal-tar, sulphate of ammonia, and gas was erected, the gas being piped to a 50,000 cu. ft. gas storage tank. From this tank about half of the coke-oven gas is returned for heating the coke ovens in the regenerators, and the balance is

available as fuel for general works' use. The annual output of by-products recovered from the operation of the 150 Wilputte ovens is approximately 16,750 tons of tar, 7,050 tons of sulphate of ammonia, and 4,620 million cubic feet of surplus gas.

The new Duplex plant was built with a view to further extensions and a site was chosen for it east of the railway line to Tatanagar. In conjunction with this plant, a new blooming mill, rail and structural mill, sheet-bar and billet mill, sheet mill and merchant mills, all electrically driven, were erected on adjoining sites to that of the Duplex plant.

Soaking Pits (Fig. 1, Item ⑪ No. 42):

The ingots, after being stripped, are shunted by steam locomotive on 36-in. gauge tracks to the blooming mill soaking pits building and placed by means of one of two 7½-ton, 76½-ft.-span Alliance soaking pit charging cranes into one of a series of eight producer-gas fired 4-hole soaking pit furnaces served by three 10-ft.-diameter Morgan gas machines. A 5 ft. 6 in. gauge electric ingot bogie, controlled by a man riding on a trailer, carries the heated ingots to the blooming mill ingot feed table. (For figure 1, see page 304.)

Blooming Mill (Fig. 1, Item ⑪ No. 43):

The blooming mill building measures 150 ft. by 216 ft., and the blooming mill itself is a 40-in. Mackintosh-Hemphill 2-high reversing mill, being a duplicate of the blooming mill of the Youngstown Sheet and Tube Company, Youngstown, Ohio, and will roll steel ingots into slabs for the plate mill; blooms for rails, structural shapes and billets; and roughed-out blanks for 20-in. and 24-in. beams. The pinions, which have a diameter of 40 in., are made of forged steel and run in oil in hermetically closed housings, while the steel blooming rolls have a length of 80 in. with a diameter of 33 in. The mill is driven by a General Electric 5,600 h.p. continuous rating 600-volt, d.c. double motor, with a flywheel motor generator set of one 4,000 h.p., 3,000-volt, induction motor, and three 2,000 k.w. continuous rating 600-volt generators and a 50-ton flywheel. The motor and generator fields are excited by a 150 k.w. motor generator set. The control equipment includes a liquid slip regulator which automatically controls the power in-put to the drive. This motor is able to take peak loads of

22,000 h.p. The mill is served by the necessary motor-driven roller tables fitted with 18-in.-diameter steel rollers on the entering and delivery side, and is equipped with a hydraulically operated manipulator on the entering side of the mill only. Provision has been made for the future installation of an auxiliary manipulator on the delivery side. An 800-ton hydraulic vertical shear in the delivery table shears the slabs, blooms, and blanks into required lengths, both knives of the shear being moveable. The upper knife is dropped by gravity upon the bloom and held in position while the lower knife does the cutting. The crop-ends drop through a chute on a conveyor and are carried under the floor to wagons on 5 ft. 6 in. gauge tracks in the hot hole alongside the mill for movement to the open hearth stationary furnaces, where they are remelted.

Following the shearing, a rope transfer carries material to be finished in the rail and structural mill to a double table, which delivers blooms and blanks either direct to this mill or to the furnace building for reheating, the latter being the usual course. In the furnace building are two regenerative reheating furnaces for blooms, each of these furnaces having a hearth 18 ft. 6 in. wide and 34 ft. 0 in. long. These furnaces are served by two Alliance 8-ton rotating charging-cranes, one usually being kept in reserve. The charging crane picks up the hot blooms in a pair of jaws and transfers them to the reheating furnaces, which are heated by either coke-oven gas or coal tar or both these fuels together. No. 1 furnace is fitted with four charging doors and will take 24 rail blooms, 6 through each door. This furnace at present is built with an ordinary arched roof, and both coke-oven gas and coal tar are generally employed for heating, the consumption of coal tar being approximately 15 tons every 24 hours. No. 2 furnace is constructed with five charging doors and is capable of holding 30 rail blooms, 6 through each door. This furnace was completed in June last and has been built with a suspended flat roof, which is considered to be a very great improvement on the customary arched roof. It is intended to build a similar type of roof on No. 1 furnace when the present roof needs renewing. No. 2 furnace is fitted for either burning coke-oven gas or tar, but the former fuel is usually employed for heating this furnace. All slabs and such blooms that will not be

rolled out immediately following the blooming are pushed on hydraulically operated rack transfers, which deliver slabs on a slab piler and blooms either on the ground or into bloom cradles. The delivery end of both transfers is located in the so-called hot hole, a crane runway paralleling the mill building, which also serves as a shipping and storage yard and is served by a 90-ft.-span Alliance crane. The mill itself is served by a 50-ton 75-ft.-span crane over the mill, shear, and tables, and a 50-ton 75-ft.-span crane is provided for the motor house, each crane being provided with a 15-ton auxiliary hoist. This new blooming mill is capable of rolling much more steel than all the present melting furnaces can supply, its capacity being about 800,000 tons of $3\frac{1}{2}$ -ton to $5\frac{1}{2}$ -ton ingots per annum.

As stated previously, blooms for rails and structural sections, and roughed-out blanks for larger size beams rolled in the blooming mill, are sent over a rope transfer on a double roller table, one side of which delivers them either direct to the new rail and structural mill to be rolled out on the initial heat, while the other side delivers the blooms to the furnace building for reheating. The reheated blooms are again placed on the double table and sent to the rail and structural mill.

Rail and Structural Mill (Fig. 1, Item ⑪ No. 45):

This mill was built by the Mackintosh-Hemphill Company and consists of an intermediate train of two stands of 3-high rolls, 30-in. diameter for roughing 20-in. and 24-in. beams, and 28-in. diameter for all other sections. The mill is driven by a General Electric 6,300 h.p. continuous rating 600-volt motor with a flywheel motor generator set consisting of one 6,500 h.p., 3,000-volt, induction motor, and two 2,500 k.w., d.c., 600-volt, generators and a 50-ton flywheel. The motor and generator fields are excited by a 150 k.w. motor generator set and the control equipment includes a liquid slip regulator, similar to that for the blooming mill motor. These stands are served by four travelling lifting tables, two on each side of the mill, with intermediate front and back tables for each stand, connected by mechanically operated transfers to handle blooms after

they have been rolled out to a length exceeding the length of the travelling tables.

The finishing mill consists of a single stand of 28-in. 2-high rolls for all sections, located 218 ft. 11 in. back of the second roughing stand of the 3-high mill, and is driven by a 1,400 h.p. normal, 2,800 h.p. maximum, 250-volt d.c. motor with Ward-Leonard speed control for a range of 80 to 115 r.p.m., and a 1,100 k.w. motor generator set.

Foundations were built so that in the future an independent roughing stand can be installed ahead of the 3-high mill, which will increase the tonnage output, and lessen the work now to be done on the blooming mill and the number of roll changes.

Rails, after leaving the finishing stand, are sawn to 30-, 36-, or 40-foot lengths. A set of four adjustable hot saws is provided, so that three rails can be cut at the same time. The rails then pass through a cambering machine and a stamping machine to either of two hot beds, each consisting of two independently operated halves, each half capable of taking 40-foot rails. After the rails are cooled by travelling over the full length of the hot bed of 148 feet, they pass to the rail finishing department where they are straightened, gagged, ended, and drilled. The equipment includes a rail roller straightener, six units of one-gag straightener, two rail ending machines, and two drill presses.

The finished rails then pass outside the building to a dock 910 feet long, where they are inspected. A crane runway covers the inspection and loading dock, from which the rails are loaded on wagons by two 20-ton 85-ft.-span Alliance cranes, carrying specially designed rail-lifting magnets. Two loading tracks extend through the centre of the docks. These tracks are depressed so as to bring the wagon floor level with the docks. A cold saw department is included for re-sawing rejected rails into odd lengths.

At present the new 28-in. finishing mill is insufficiently equipped for the rolling of structural material, but as stated in the paragraph on future developments (p. 303), it is intended to fully equip this mill to roll structural material in the near future. Structural shapes, after leaving the finishing mill, will then be hot sawn by a 60-in. sliding frame saw provided

with a gauge for cutting up to 80-foot lengths. The material will then pass to the hot beds, the two 40-ft. halves of either bed being connected in this case to form an 80-ft. hot bed. After travelling the length of the hot bed, all sections will be delivered over roller tables into an existing structural finishing, storage, and shipping yard. This yard consists of three 360-ft. crane runways, each served by an 81-ft.-span Alliance crane with two 5-ton trolleys. In a section covered with corrugated sheeting, structural finishing machines, such as roller and gag straighteners, shears, cold saw, etc., together with necessary tables and transfers, will be installed.

Crane equipment over the mills and tables includes the following Alliance cranes: one 80-ton 70-ft.-span crane, and one 25-ton 70-ft.-span crane.

A separate motor house was built in which is located the blooming mill motor and the motor for the 3-high mill. They are supplied with cooled air from air washing equipment having a capacity of 200,000 cubic feet of air per minute. In this motor house are also placed the following general mills service units: two 1,500 k.w. motor generator sets for supplying direct current for cranes and auxiliary motors, and a motor-driven air compressor and three motor-driven hydraulic pumps, each having a capacity of 700 gallons per minute against 550 lb. per sq. in. pressure.

The capacity rating of the rail and structural finishing mill is at least 500,000 tons of rails and structural shapes per annum.

Sheet-Bar and Billet Mill (Fig. 1, Item ⑫):

A new sheet-bar and billet mill was built by the Morgan Construction Company, and consists of six stands of 24-in. continuous rolls and 6-stands of 18-in. continuous rolls, capable of rolling up to 15 in. wide, and further reduces blooms and slabs into billets for the merchant mill, sheet-bars for the sheet mill, sleeper bars for the sleeper press plant, and tin bars for the Tinsplate Company of India, a subsidiary firm situated at Golmuri about 3 miles from Jamshedpur. All these sections, except sleeper bars, are rolled direct after passing through the blooming mill without any reheating.

The mills are driven by General Electric motors through Falk speed-reducing gear sets, a 2,300 h.p., 3,000-volt, motor being provided for the 24-in. mill, and a 4,000 h.p., 3,000-volt, motor for the 18-in. mill. A 30-ton 82-ft.-span Alliance crane, with a 10-ton auxiliary hoist, serves the mill and equipment. The 24-in. and 18-in. mills are connected by a roller table with skewed rollers, which allows the delivery of material in a broadside transfer to roller tables, and to an Edwards steam flying shear, by which the material is cut to length. These roller tables and shear are situated outside the building, under the storage and shipping yard crane by which the material is loaded for shipment.

Connected to the end of a roller run, and located under the mills stockyard cranes, is a 30-ft. by 84-ft. cooling bed with an incoming table equipped with skewed rollers, and the delivery end consisting of cradles mounted on the platform of a 30-ton scale. For handling sheet bars, a bar piler is mounted on the incoming skew table. This sheet-bar and billet mill is capable of a production of 207,500 tons of billets, sheet and tin bars, and sleeper sections per annum.

Plate Mill (Fig. 1, Item ⑬):

Included in these greater extensions was the erection of a new plate mill. Slabs from the blooming mill hot-hole, or ingots from the open hearth, are delivered on wagons to a storage yard 616 feet long. A 15-ton 97-ft.-span Alliance crane, equipped for lifting the stock with magnets, places the ingots or slabs alongside the furnace building, where they can be picked up by the peel of two 8-ton 45 ft. 9 in. span Alliance revolving charging cranes and placed in the regenerative heating furnaces, of which there are three. These furnaces are each provided with four charging doors and have 9 ft. by 34 ft. hearths. They are capable of heating 24 small slabs (88 in. max. length by 28 in. wide by 3 in. thick) or 10 large slabs (88 in. max. length by 28 in. wide by 8 in. average thickness) at one time. The furnaces are heated by means of coke-oven gas, tar, or crude oil, each furnace being provided with the necessary burners. When burning tar or crude oil, steam is used for atomising the fuel, the following being the average working pressures — tar 60 to 80 lb. per sq. in.; crude oil

40 to 60 lb. per sq. in.; and steam 120 to 140 lb. per sq. in. Two tanks, each of 24,000 gallons capacity, are located in a pit for storing the necessary tar or oil, which is pumped to the burners, three tar pumping sets being provided. Tar is pumped through pipes to these storage tanks from the coke ovens by-product plant, and the tanks in turn supply tar to the calcining plant and Duplex plant storage tanks when required, there being pipe lines from the plate mill to these plants. After heating, the slabs are taken out of the mill by means of a rope-propelled slab car.

The plate mill, which is capable of rolling plates up to 7 ft. wide and from 3/16-in to 1 1/4-in. thick, is a 96-in. United Engineering and Foundry Company's tandem mill, consisting of a 3-high roughing stand followed by a 3-high finishing stand, each stand being equipped by hydraulically operated lifting tables in the front and back of the mills. Each stand is direct driven through a set of Falk speed-reducing gears by a General Electric motor, and each drive has a 15-ft.-diameter flywheel. The roughing stand motor is of 2,000 h.p., and the finishing stand motor 2,500 h.p. These motors are located in a separate motor house, which also contains air washer apparatus, air compressor, and hydraulic pumps. This equipment is served by a 30-ton, 55-ft.-span, Alliance crane, and in the equipment is included a roll turning device, which allows rolls to be turned in the mill stands.

After leaving the finishing mill, the plates pass over roller tables through a nine-roll Newbold straightening machine, after which they are cooled on a chain conveyor and passed to an inspection table. This table is equipped with arms which lift the plate so that the under side can be inspected as well as the top side. After inspection, the plates are passed on to a second chain conveyor for final cooling and marking before going to the shear table.

Shearing equipment consists of one Newbold double rotary trimming shear, capable of shearing the edges of mild steel plates from 1/4-in. up to and including 1-in. thick, and from 18-in. to 100-in. wide; two Southwark hydraulic cross-cut shears for shearing to length and for irregular plates; one Newbold rotary circle cutting machine, capable of cutting circular plates 1-in. thick and 11 ft. 6 in. diameter down

to $\frac{1}{4}$ -in. thick and 2 ft. 2 in. diameter; and also two vertical shears for cutting up the scrap. For the easy handling of plates at the cross-cut shears and the circle cutting machines, the area around these shears extending to the scales is covered with roller ball-bearing casters. A 6-ton scale with 41-ft. platform is used for weighing all plates before shipping. A 30-ton 60-ft.-span Alliance crane with a 10-ton auxiliary hoist serves the mills, and a 10-ton 97-ft.-span crane equipped with plate handling magnets serves the finishing and shipping building. The chain conveyor building contains two 5-ton hand power travelling cranes with trolleys and hoists. The plate mill is capable of producing over 500,000 tons of plates per annum.

Sheet Mill (Fig. 1, Item ⑭):

For producing plain and corrugated galvanized and black sheets, a sheet mill was purchased from the United Engineering and Foundry Company, consisting of 9 finishing mills together with 4 roughing stands, one drag and two cold mills. Facing the mill from the rollers or furnace side, the stands are arranged from left to right as follows: 29-in. by 29-in. drag rolls; 30-in. by 48-in. finishing rolls; 30-in. by 48-in. jump roughing rolls; two stands 30-in. by 48-in. finishing rolls; 30-in. by 48-in. balanced roughing rolls; pinion stand; 30-in. by 66-in. balanced roughing rolls; 30-in. by 66-in. finishing rolls; motor and gear drive; 30-in. by 42-in. finishing rolls; 30-in. by 42-in. jump roughing rolls; 30-in. by 42-in. finishing rolls; and three stands of 30-in. by 36-in. finishing rolls. Coupled with these stands, and operated from the same drive, are the cold mills, with one stand of 26-in. by 42-in. rolls and one stand of 26-in. by 54-in. rolls. All mills are driven through reducing gears from one General Electric 1,500 h.p., 3,000-volt, induction motor.

Heating furnace equipment consists of the following Hagan furnaces: six sheet furnaces, six pair furnaces, and three combination sheet and pair furnaces. All furnaces have water-cooled fronts, mechanical stokers and blowers for coal firing, and independent coal bunkers. The furnaces are charged by hydraulic pushers with the necessary hydraulic pump and accumulator equipment. The furnace building contains a 15-ton 57-ft.-span Alliance crane. Coal for the

furnaces is unloaded over a 5-ft. 6-in.-gauge track hopper outside the building, the discharge end extending into the furnace building, and is taken to the coal bunkers by means of a grab bucket on the crane.

Sheet bars are delivered to the approach table of a bar shear, extending into the mills stockyard, and, after shearing, are delivered by the furnace building crane to the heating furnaces.

Auxiliary equipment in the sheet mill building includes one 66-in. motor-driven hot sheet leveller, six 54-in. steam doublers, three 156-in. and one 126-in. motor-operated squaring shears, scrap baling press with mono-rail, and magnet for handling baled scrap. A continuous annealing furnace is provided with annealing boxes and bottoms. The operating floor around the mills is water cooled and washed air is supplied for the operators and for cooling the mill motor. A 30-ton 97-ft.-span Alliance crane, with a 10-ton auxiliary hoist, serves the mill, and a 50-ton 97-ft.-span crane the annealing end of the mill building.

In the pickling and galvanizing building are located two Mesta pickling machines, three 42-in. and one 48-in. galvanizing machines, each with cooling wheel, and a motor-driven 48-in. cold leveller, all covered by a 15-ton 82-ft.-span Alliance crane.

The finished sheets are taken into a warehouse 556 feet long served by a 10-ton 97-ft.-span Alliance crane and containing a roll corrugating machine, a corrugated press, a corrugated curving machine, a 156-in. squaring shear, and other accessories such as trucks, scales, etc. The sheet mill is capable of producing 36,000 tons of sheets per annum.

Merchant Mill (Fig. 1, Item ⑮):

Also included in the greater extensions was the erection of a merchant mill. Billets from the sheet-bar and billet mill are placed by the stockyard crane on a furnace charging conveyor extending into the mills stockyard, and are sent through a Morgan 25-ft. by 30-ft. continuous heating furnace, for which either coke-oven gas or coal tar is employed as fuel. The heated billets are pushed out of the furnace, and a set of

pinch rolls forces the material through a flying shear. From this point the stock passes through a Morgan mill consisting of the following units:

A 16-in. edging mill, preceding six stands of continuous 14-in. mill, and a cross-country type 12-in. mill of two trains of two stands each. These mills are driven by one General Electric 2,250 h.p., 3,000-volt, mill-type motor with speed regulating set and magnetic control. For the rolling of wire rods or similar small sections, an auxiliary 8-in. finishing mill is provided, consisting of two stands in line with the second train of 12-in. mill and individually driven by a General Electric 600 h.p., 3,000-volt, mill-type motor, with speed regulating set and magnetic control.

The finished material from the 12-in. mills, and all products from the 8-in. auxiliary mill that cannot be shipped in coils, is delivered to an Edwards escapement-type cooling bed 300 feet long, followed by a bar-shear. At the end of the back shear table is located a roller straightener. All wire rods and similar product from the 8-in. mills which has to be coiled, is taken by two Edwards automatic pouring reels, followed by a rod bundle conveyor and hook carrier, which deliver the rod bundles direct to the shipping wharf. The mills and equipment are served by a 15-ton 95-ft.-span Alliance crane. The merchant mill can produce an annual output of 100,000 tons, and the products are $\frac{1}{4}$ -in. rods, $\frac{1}{2}$ -in. to 2-in. rounds and squares, $\frac{3}{4}$ -in. by $\frac{1}{8}$ -in. to $4\frac{1}{2}$ -in. by $\frac{1}{4}$ -in. and thicker flats, and 1-in. by $\frac{1}{8}$ -in. to 3-in. by $\frac{1}{4}$ -in. angles.

Between the sheet-bar and billet mill on one side, and the merchant mill and sheet mill on the other side, is located, at right angles to these mills, a 120-ft.-span crane runway, 880 feet long, covering the cooling bed of the sheet-bar and billet mill and serving as a stock yard for the sheet mill, the merchant mill, and the pressed sleeper shop. Part of this runway (265 feet in length) is roofed over to protect the sheet mill stock. Two cranes are installed in this yard, for handling raw material to the mills, one having a single 15-ton trolley and the other two 10-ton trolleys.

The mill buildings throughout are placed due east and west with protected gables and open north and south elevations. This procures, in the latitude of Tatanagar (where the declina-

tion of the sun from its zenith is $0^{\circ} 30'$ north at midsummer and 42° south at midwinter) continuous shade in the interior of the buildings, and at the same time free circulation of air. The building frames are of steel and of heavy design, so as to withstand the occasional tropical storms. The columns are not less than 34 feet high and the roofs are of corrugated puddled iron sheets.

The greater extensions programme included a bolt and nut shop, containing plant for the production of rivets, bolts, nuts, track spikes, and screw spikes, etc.

At the south end of the existing crane runway serving the rolling mills, a building was constructed to serve as a roll shop for the old mills and plate mill, and contains the necessary roll lathes.

To increase the facilities for fabricating structural work for plant use, as well as for sales from material rolled at Jamshedpur, a new structural shop was included in the greater extensions programme. This shop has a floor area of 38,016 sq. ft. and is fully equipped with the necessary tools, including a set of plate bending rolls capable of bending $\frac{3}{4}$ -in. plates 16 feet wide, or 1-in. plates 9 feet wide.

An assembling and shipping yard is provided and is served by a travelling crane.

A second machine shop was built with a floor area of 50,400 sq. ft. and equipped with a complete set of modern machine tools of wide range, and also necessary cranes.

The iron foundry was improved by extending the crane runways over the casting, clearing, and storage yard, thereby increasing the moulding space. Jib cranes were installed to serve the moulding floor, and a 7-ft. by 10-ft. Herman compressed air moulding machine for mechanical moulding.

In connection with the enlargement of the iron foundry a pattern shop with wood-working tools and space for pattern storage was built.

The forge shop equipment was increased by the addition of a 500-ton high-speed Davy steam forging press. This press was installed outside the forge shop and is served by a hand-operated travelling crane, sent to India with the Batelle blast furnace.

A sleeper press shop was also constructed where sleeper bars, rolled in the sheet-bar and billet mill, are reheated and then taken to either of two hydraulic presses for shaping into sleepers. The capacity of each press is at the rate of 75 sleepers per hour. From the presses, the sleepers are conveyed through a tar bath and cooled, after which they are ready for shipment.

The power requirements of the enlarged plant and the demands for power to be furnished to newly formed subsidiary companies in the neighbourhood of Jamshedpur (including the Tinplate Company of India, which manufactures tinplate from tin bars supplied by the Tata Company; the Indian Steel Wire Products Company, which converts wire rod obtained from the Tata Company into plain and galvanized wire, fencing wire, and wire nails; and the 'Agrico' Company, which manufactures agricultural implements) resulted in the installation of the following additional power generating equipment: one 4,200 k.w., one 5,000 k.w., and two 10,000 k.w. General Electric turbo generators furnishing 3,000-volt alternating current, together with a 750 k.w. motor generator set to provide direct current for auxiliary motors at 'C' and 'D' blast furnaces and other units in this vicinity. These machines were installed in No. 2 power house with the furnace blowing equipment in order to centralize attendance and decrease the length of high-pressure steam mains. They are equipped with Wheeler low-level jet condensers.

Several substations were constructed where the direct current requirements of the different plant units are taken care of, as follows: No. 2 substation, in the plate mill motor house, contains one 750 k.w. General Electric motor generator set and one 600 k.v.a. transformer bank; No. 3 substation, in the blooming mill motor house, contains two 1,500 k.w. General Electric motor generator sets and one 600 k.v.a. transformer bank; No. 4 substation, in the Bessemer converter blower house, contains one British Thomson-Houston 500 k.w. motor generator set, and recently one General Electric 750 k.w. motor generator set has been installed.

Alternating current (3,000-volt) is supplied to the subsidiary companies. For recording purposes, the current is furnished to a meter house on the property of the subsidiaries,

from which these companies continue their own transmission, transformation, and distribution.

To meet the increased demand for water, the main pumping station at the Subarnarekha river was extended and three additional Sulzer pumps of 4 million gallons daily capacity each were installed. For the supply of water to the original plant, a powerful pumping station containing three Sulzer 4 million gallons daily capacity pumps had been built on the edge of the Subarnarekha river, the first necessity having been to throw across the river a low dam about 1,200 feet long in order to bank up the river water to obtain suction for the pumps. The level of the river is about 140 feet below that of the works, and the intervening distance is nearly two miles. The water was pumped through a 36-in.-diameter pipe-line into a cooling reservoir within the works in order to ensure an adequate supply of water at all seasons. This original reservoir was formed in a small natural valley on the site, across which a dam about $\frac{1}{2}$ -mile in length was constructed. The area of the reservoir is about 64 acres; it has a depth which at one point reaches 67 feet, and is capable of impounding 241 million gallons of water. The water was taken by other pumps into the works, returned along shallow cooling ditches into the reservoir, and used again and again. Even if the river temporarily ran dry, which it almost does during the months of April and May, there would thus be ample water available. Two filter beds were also provided for supplying water to the boilers and the town.

The installation of large condensing, blowing, and power-generating machines, and the spreading of the new plant units over a greater area, necessitated greater facilities for water distribution than could be obtained by additions to the existing pumping station. A second power house was therefore built, containing ten 12,000-gallons-per-minute Alberger centrifugal pumps, driven by General Electric motors, six for water supply to the condensers in No. 2 power house and four for general plant service; and two 6,000-gallons-per-minute steam turbine-driven centrifugal pumps to serve as a standby in case of interruptions in the electric service. Four travelling screens are provided in the intake to this pump house, and a 10-ton Alliance crane serves this building.

In connection with the water supply, the existing cooling reservoir was found to be inadequate, and a second larger reservoir was constructed adjoining the original one, capable of impounding 1,150 million gallons of water. The water level of the new reservoir is 15 feet below the level of the old reservoir, and by raising the dam it will be possible to increase the capacity of the new reservoir materially, if found necessary. A gate house was installed near the east shore of this reservoir, connected by a tunnel with pump house No. 3, containing two 10,500-gallons-per-minute Alberger centrifugal pumps with General Electric motors. These pumps lift the water from the new low-level pond into the original pond for service to pump house No. 3.

A system of distributing and return mains connected with the existing pipe lines were laid. The complete water system includes necessary fire lines and provisions for drinking water, together with a soda-water factory, and a refrigerating plant containing ice-making machinery, which produces 15 tons of ice daily for use in the works and town.

A system of coke-oven gas distributing mains was also installed, by which the waste gas from the operation of the coke ovens is collected (and will be de-benzolized in the benzol plant when this plant is completed), and the surplus gas piped through cast-iron pipes to a 50,000 cu. ft. capacity gas holder, and thence to the various furnaces, etc., heated by this fuel. In order to secure the necessary pressure to force the gas to the most distant points of consumption, a booster station was installed containing three motor driven Roots' gas boosters.

Other additions to the works plant include an additional boiler plant (No. 4), containing eight 1,000 h.p. units of Babcock & Wilcox horizontal water tube boilers with super-heaters. These boilers are stoker fired, each boiler being equipped with two Green chain grate stokers. As a small amount of steam was required by the new finishing mills which are located at too great a distance from the main boiler plants, Nos. 1 to 4, a further small boiler plant (No. 5) was built, containing two 250 h.p. coal-fired boilers, arranged for hand firing.

For the supply of additional raw materials, the iron ore mines at Gurumahisani were further developed along with mines at Sulaipat, and Badampahar mine was mechanically

equipped. Limestone quarries were also developed and colliery holdings increased.

To take care of the increased movement of incoming raw materials and outgoing products, as well as inter-works shunting of material, extensions to the railway track system became necessary, and it now consists of 50½ miles of 5-ft. 6-in.-gauge, 1¼ miles of 3-ft. 0-in.-gauge, and 12¾ miles of 2-ft. 0-in.-gauge tracks. These extensions consisted of double tracking the line to the Bengal-Nagpur railway shunting yard at Tatanagar, a plant classification yard, and the necessary railway connections to the coke ovens, blast furnaces, and mills. Additional track scales, a locomotive coaling station, and a locomotive shed, were also included.

Additional rolling stock had to be provided and the following equipment was found necessary to ensure uninterrupted service to and from all departments: Twenty-one 5-ft. 6-in.-gauge locomotives, two being constantly engaged in the Duplex plant; five 3-ft. 0-in.-gauge locomotives, three being employed in the Duplex plant, and two in the stationary open-hearth plant; two 2-ft. 0-in.-gauge locomotives, which are used solely for conveying sand from the Subarnarekha river to the blast furnaces; twelve 5-ft. 6-in.-gauge locomotive cranes of a capacity from 15 to 40 tons, one 30-ton crane being solely engaged for Duplex plant work; thirty coke hopper, ten coal hopper, and three ash hopper, wagons; four billet wagons; sixty-three flat wagons; twenty-one gondolas; two 30-ton tar tank, and one acid tank, wagons; one scale test wagon; and miscellaneous wagons and equipment for handling ashes and plant refuse, etc. Adjacent to the stationary open-hearth plant is a brick building containing testing machines and physical and chemical laboratories, and a separate chemical laboratory is located on the Duplex open-hearth platform.

The cost of these greater extensions amounted to approximately 171¼ million rupees or nearly 13 million pounds sterling, and during the extensions over 25 million cubic feet of earth were removed, about 4 million cubic feet of concrete were utilized for the foundations, and the brickwork amounted to nearly 900,000 cubic feet.

The rapid growth of the steel works may be judged by the fact that in 1926 the Company manufactured over 624,719

tons of pig iron, 10,215 tons of ferro-manganese, and 525,451 tons of steel ingots, most of the steel being rolled into rails, fish-plates, structural sections, bars, plates, sheets, tin-bars and steel sleepers.

To illustrate the general lay-out of the Tata Iron and Steel Works, a plan (Figure 1) is given, with accompanying key (Table I).

(c) *Future Developments*

With reference to further developments, it is intended to make the following additions and alterations to existing plant in the near future:

Coke ovens.—One new battery of Wilputte coke ovens similar to the three existing batteries will be built, as it is not possible to manufacture sufficient coke at present to supply all the five blast furnaces.

Benzol plant.—A benzol recovery plant is to be installed in which the coke-oven gas, before passing to the present gas holder, will go through a group of oil scrubbers fitted with wooden grids in such a manner that oil, which is allowed to trickle through the grids from a series of sprays at the top, comes into intimate contact with the gas. This so-called wash-oil will absorb 90 to 96 per cent of all the benzol vapours of the gas. The wash oil, thus saturated with benzol and its homologues, will then be pumped through pre-heaters into light oil stills at the benzol plant.

Here the oil will be brought in contact with steam, and benzol vapours will thereby be driven off, condensed, and separated from the water, and will form what is known as light oil. The wash oil, de-benzolized, will then be cooled and returned to the oil scrubbers for another cycle.

The light oils coming from the light oil stills will contain approximately 8 per cent of wash oil and naphthalene, which will be separated by distilling the light oils in an intermediate still known as a crude still. Approximately 92 per cent of the benzol and its homologues will be distilled off, leaving a residue of naphthalene and wash oil. This residue will then be drawn off and forced into cooling pans, where the naphthalene will be crystallized and the wash oil returned to the circulating system.

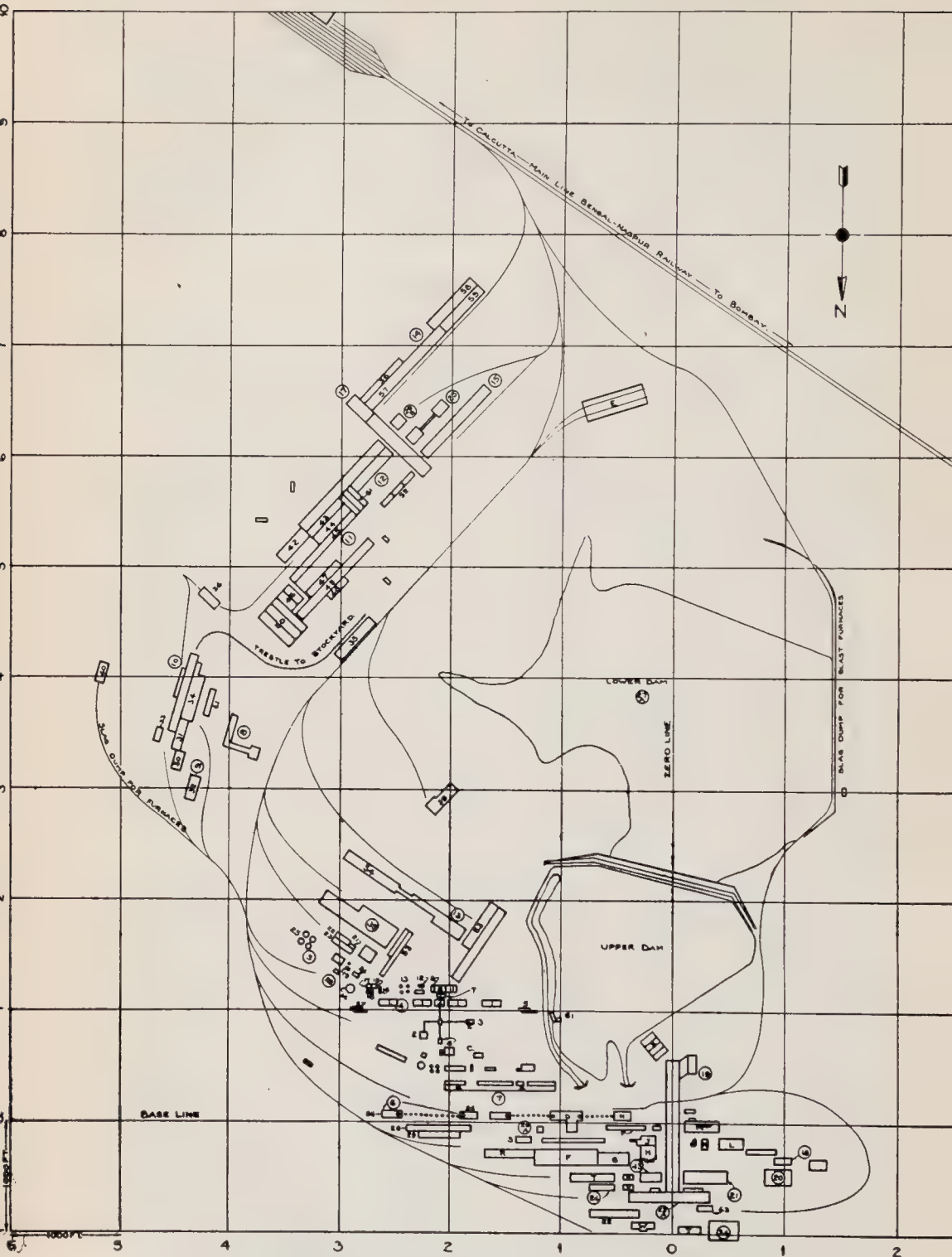


Figure 1.—General plan of the works of the Tata Iron and Steel Company, Limited, Jamshedpur, India.

Table I. Key to general plan (see figure 1)

A. Coppée coke ovens	M. Bar mills
B. Koppers coke ovens	N. Power house No. 1
C. By-product plant for Koppers ovens	P. Boiler house No. 1
D. Blast furnaces 'A' and 'B'	Q. Crane runway for mills and shops
E. Drag ovens (now discarded)	R. Open-hearth stock yard
F. Stationary open-hearth furnaces — 1 to 7	S. Calcining plant
G. Pit furnaces	T. Brick storage
H. Blooming mill	U. Works office
J. Rail and structural mill.	V. Storehouse
K. Rail cooling beds	W. Iron sleeper foundry
L. Rail finishing dept.	X. Filter beds
	Y. Accountants office.

Greater Extensions

④ Coke Plant

1. Wilputte ovens
2. Coal handling apparatus
3. Coal crushing plant
4. Coal bin
5. Coke quenching stations
6. Coke screening station
7. Primary gas coolers
8. Exhauster and saturator room
9. Still room and lime mixing room
10. Pump room
11. Sulphate storage room
12. Lime house
13. Tar and ammonia tanks
14. Fuel gas holder
15. Final gas coolers
16. Naphthalene settling basin

⑤ Benzol Plant (Erection not yet completed)

17. Gas scrubbers
18. Wash oil pump house
19. Oil to oil heat exchanger
20. Still building
21. Naphthalene pans
22. Loading dock
23. Product tanks
24. Wash oil coolers
25. Storage tanks

⑥ Blast Furnaces 'C' and 'D'

26. Cast houses
27. Stoves
28. Boiler plant No. 3
29. Power house No. 2

⑦ 'Batelle' Blast Furnace 'E'

⑧ Pig Casting Plant

⑨ Mixer and Converter Plant

30. Mixer building
31. Converter building
32. Bottom house
33. Blowing engine house

⑩ Duplex Open-Hearth Plant

34. Tilting open-hearth furnace building
35. Stock yard
36. Ingot stripping yard
39. Calcining plant
40. Skull cracker
41. Gas producer plant

⑪ Blooming Mill, Rail and Structural Mill

42. Soaking pits
43. Blooming mill
44. Motor house
45. Rail and structural mill
46. Rail and structural hot beds
47. Rail finishing department
48. Cold finishing department
49. Rail loading dock
50. Structural finishing yard
51. Reheating furnaces
52. Roll shop

⑫ Sheet Bar and Billet Mill

⑬ Plate Mill

53. Reheating furnaces
54. Plate mill

⑭ Sheet Mill

56. Furnace building
57. Sheet mill and annealing department
58. Pickling and galvanizing building
59. Warehouse

⑮ Merchant Mill

⑯ Stock Yard for Mills

⑰ Bolt and Nut Shop

⑱ Roll Shop

⑲ Structural Shop

⑳ Machine Shop No. 2

㉑ Pattern Shop

㉒A Iron Foundry

㉓ Forge Shop

㉔ Sleeper Press Plant

㉕A Lower Dam

61. Pump house No. 2
62. Lower dam pump house
63. Ice plant

㉖ Coke Oven Gas Booster Station

㉗A Boiler Plant No. 4

㉘B Boiler Plant No. 5

㉙ General Office Building

㉚ Structural Shop (Jessop & Co., Ltd.)

㉛ Machine Shop No. 1 Extension

In this crude distillation, the total benzol fractions, with the exception of what is known as the heavy No. 2 solvent, will be combined, while the heavy solvent will be separated. The combined benzol fractions will then be pumped into a lead-lined agitator, and 66 per cent sulphuric acid added, and the contents agitated for a period of three hours, after which the sludge, consisting mainly of thiophenes and unsaturated hydrocarbon compounds, will be removed and drawn off into an acid pot. After the benzol has been sufficiently washed with acid, as determined by laboratory tests, it will be washed with water and neutralized with a 10 per cent solution of caustic soda. The water and caustic soda will then be drawn off and the washed benzol product pumped to the pure stills where the product can be either fractionated into benzol, toluol, and solvents, or refined into motor fuel, according to market requirements.

For the refining of motor fuel, the annual yield of this plant would be about 1,255,000 Imperial gallons.

Duplex plant.—A third 25-ton Bessemer converter is to be installed, and additions to electrical equipment will be made to enable two converters to be blown simultaneously, instead of one at a time as at present.

A third 200-ton Duplex open-hearth tilting furnace of the same type as the two existing ones will be erected, as the steel capacity of the present open-hearth plants is much below the capacity of the rolling mills.

It is also proposed to erect a cupola to remelt spiegel for recarburizing steel in the ladle.

A new 800-ton hot metal mixer is also to be installed in the Duplex plant to take care of blast-furnace metal for the increased requirements of the Duplex open-hearth furnaces.

A new stripper yard is now being equipped with a 200-ton stripper crane and gantry to facilitate the stripping of ingots from both the Duplex and stationary open-hearth plants.

It is also intended to erect three new vertical calcining kilns, as the capacity of the existing kilns will be insufficient to supply the open-hearth furnaces with burnt lime and dolomite for an increased steel production.

Stationary open-hearth plant.—In order to increase the output of steel from this plant, it is intended to convert the

four old open-hearth furnaces (Nos. 1 to 4) from 55 to 90 tons capacity.

In connection with these furnaces, Morgan mechanical gas machines of the same type as those already in operation at the Duplex plant will be installed in order to economize fuel.

Soaking pits.—It is intended to construct two new soaking pit furnaces for the blooming mills, and instal another soaking pit charging and drawing crane to take care of the additional steel to be produced from the third Duplex open-hearth furnace.

Blooming mill.—A new automatic manipulator is to be installed at the shear side of the blooming mill cogging rolls.

Two additional reheating furnaces for billets from the blooming mill will be built, making four furnaces in all.

Rail and structural mill.—An additional roughing mill is to be installed, and the existing new 28-in. mill is to be equipped with a finishing department for structural material, as it is not possible at present to roll structural material with this mill. When the new 28-in. mill is properly equipped for the rolling of structural material, it will be possible to shut down the old and comparatively inefficient 28-in. mill in the old plant, and use the new mill at its full capacity.

Hoop and strip mill.—The erection of a hoop and strip mill is contemplated to enable the Tata Company to roll strip, which is a very essential requirement of the agricultural products of India. This mill will also enable the Company to supply all the lighter sections, including those required by all manufacturers of drawn-steel wire.

Sheet-bar and billet mill, and sheet mill.—It has been found that the motors driving these mills are not sufficiently powerful, and in order to get full production and to deal with the increased quantity of steel, additional motors are required.

A second hot bed will also be constructed for the sheet-bar and billet mill, while additional mills will be installed in the sheet mill.

Plate mill.—Extensions to this mill are to be carried out and additional equipment provided.

Roll plant.—A new roll shop is to be provided, which will be served by a 15-ton 55-ft.-span Alliance crane, along with

the necessary tools and machines to enable the plant to manufacture rolls for the new mills.

Sleeper press plant.—This plant is to be extended, as its present capacity is insufficient to supply the demands for pressed steel trough sleepers.

Foundries.—These are also to be extended and additional equipment provided.

Blast furnaces.—Improved blowers are to be provided and the installation of silica-gel dry blast for 'C' and 'D' furnaces is being considered.

Brick-kilns.—The Tata Company proposes to manufacture its own chrome, magnesite, and silica bricks, which will mean a great saving in the cost of these materials. The necessary kilns are, therefore, to be constructed in the near future.

Electric power and cranes.—Various additions to the power plant will be necessitated by a larger production of iron and steel, and additional electric overhead travelling cranes will be required to handle the material.

A new electrical repair shop is also to be erected.

Rolling stock.—Additions to rolling stock will also be necessary, and a 75-ton steam travelling crane, two broad-gauge steam locomotives, and 200 broad-gauge wagons are to be purchased.

New weighbridges and tracks are to be installed, while a locomotive shed is to be constructed which will include bunkering arrangements for coal and water.

Metallurgical research department.—This department is to be started and fully equipped for metallurgical research work, as this is considered to be a necessity for the advancement of metallurgy in India.

SECTION III. DESCRIPTION OF THE DUPLEX PLANT

Before proceeding to describe the Duplex plant proper, the author considers it advisable to give a short description of the blast furnaces ⁽¹⁾ which supply molten pig iron to the Duplex plant hot metal mixer.

Blast Furnaces

There are five blast furnaces in all, 'A' and 'B' furnaces being the original units. 'A' furnace was first blown-in in 1911,

(1) These are more fully described by J. L. Keenan, "Notes on Blast Furnace Practice in India"; Jour. Iron and Steel Inst., 1925, No. II, page 45.

and 'B' furnace in 1912. These two furnaces are similar in construction and are 77 feet in height. Originally they were built with 12-ft.-diameter hearths and 19-ft.-diameter boshes, but they were enlarged in 1916 to 14-ft. 8-in. and 19-ft. 8-in. respectively, the cubical content being 14,810 cubic feet. The average daily output of each of these furnaces is 350 to 400 tons of pig iron, and the average blast pressure 11 lb. per square inch, each furnace averaging seven taps every 24 hours.

As previously stated in this paper, 'E' furnace was originally erected in Batelle, Alabama, and was dismantled, shipped to India, and re-erected at Jamshedpur in line with 'A' and 'B' furnaces with the same size hearth and bosh. The height of 'E' furnace is 81 ft. 10½-in., and it was first blown-in in 1919. It was not working for several months, but recommenced making pig iron on October 25th, 1926, the furnace having recently been re-lined. It is now producing from 400 to 450 tons of pig iron per day from eight taps, the average blast pressure being about 15 lb. per sq. in.

'A', 'B' and 'E' furnaces are equipped with large cast houses provided with 10-ton Alliance overhead cranes. The metal from these furnaces can be cast either into sand or ladles as required. All sand cast iron is broken hot by throwing it over the cast house wall on to breaking blocks directly the metal has cooled sufficiently.

The surplus gas from these three furnaces is utilized under boilers for the generation of high-pressure, super-heated steam for the operation of turbo blowers and turbo generators, and for transmission to other units requiring steam.

'C' and 'D' furnaces are more recent additions and were blown-in in December, 1922, and January, 1923, respectively, being designed along most modern lines. They are similar in size, having 17-foot-diameter hearths, with 21-ft. 6-in.-diameter boshes, and a height of 89-ft. 17⁄8-in., the cubical content of each being 22,610 cubic feet. These furnaces have almost every modern appliance, including inclined skip bridge and double skip, with electrically operated skip hoisting engine and bell control apparatus for automatically charging the raw

materials into each furnace. Each furnace is equipped with a closed top, the waste gases being carried away through a pair of down-comers, each connected to two large and one smaller auxiliary dust catchers arranged in series, which decreases the amount of flue dust in the gas and at the same time decreases the iron loss. From the final dust catcher at each furnace, the gas is carried to the boilers and stoves. The following is an average analysis of the blast furnace gas:

CO ₂	O ₂	CO	H ₂	CH ₄	Total combustible gases	B.T.U. per cu. ft. at N.T.P.
10.2%	0.4%	29.4%	1.0%	1.2%	31.6%	115.4

The gas piping system includes two Freyn-Brassert gas washers for further cleaning the gas used for stove heating by washing. The dirty water from the gas washers is passed through a Dorr thickener, which eliminates the sludge by means of agitation.

'C' and 'D' furnaces have each an independent cast house provided with an Alliance 10-ton 49-ft.-span overhead travelling crane and equipment of iron and slag runners for ladle practice only, and the iron is cast into 60-ton Pollock ladles and slag into 300-cu.ft. steam dump Pollock slag ladles and used for filling purposes. The iron ladles and slag pots are mounted on trucks for shunting the iron to the hot metal mixers or to the pig casting plant, and slag to the slag dump. The slag cars are equipped with cylinders operated from the locomotive for dumping the slag.

The stove equipment for heating the furnace air blast consists of four 24-foot-diameter by 100 feet high steel plate stoves lined with fire bricks for each furnace, or a total of twenty stoves for all the five blast furnaces. The stoves for 'E' furnace are fitted with a Hagan combustion controller. It is the practice to take full advantage of the stove heat, and stoves are therefore changed every $1\frac{1}{4}$ hours, the cold by-pass valves never being opened.

Raw material storage consists of a series of elevated overhead ore, coke, and dolomite tracks over a lorry tunnel. The materials are dropped on the tunnel and are drawn through

chutes into lorry cars, which automatically weigh and record the weight of the charge before it is dumped into the furnace skip bucket.

The average daily output of 'C' furnace is about 650 tons from seven taps, and that of 'D' furnace about 700 tons from seven taps. The average blast pressure is 15 to 18 lb. per square inch for 'C' furnace, and 17 to 20 lb. per square inch for 'D' furnace, which explains the considerably higher output obtained from the latter. Each furnace has twelve tuyeres of 5-in. or 6-in. diameter and 12-in. or 15-in. in length. The average blast temperature is about 1,150°F. (621°C.).

The blast for all the five furnaces is supplied from two power houses. 'A', 'B', and 'E' furnaces are equipped with three Escher-Wyss 40,000-cu.ft. and one 37,500-cu.ft. capacity Ingersoll-Rand turbo blowers; 'C' and 'D' furnaces with three 45,000-cu.ft. and one 37,500-cu.ft. capacity General Electric turbo blowers.

The boiler plant consists of 25 Babcock & Wilcox combination gas and coal-fired boilers; 20 Wickes gas-fired boilers equipped with superheaters, each boiler having a normal rating of 500 h.p. or a total of 10,000 h.p.; and 8 automatic coal-fired Babcock & Wilcox boilers.

For the sake of steam economy, all turbo blowers and turbo generators are operated condensing, being equipped with Wheeler low level jet condensers.

The average coke consumption for 'A' and 'B' furnaces is approximately 2,700 lb., for 'E' furnace 2,240 lb., and for 'C' and 'D' furnaces 2,200 lb., per ton of pig iron produced.

Ferro-manganese is also made as required, this alloy being manufactured by the Tata Company for the first time in India in 1916. A furnace with an old lining is usually employed periodically for this purpose owing to the much greater corrosive action than when making pig iron. The average daily output is about 75 tons, and the annual output about 10,000 tons.

The coke-oven plants have been described on a previous page. They consist of 180 Coppée non-recovery ovens, which are now idle; a battery of 50 Koppers by-product recovery ovens; and 3 batteries of 50 ovens each of the Wilputte type; a total of 380 ovens. The production capacity is approximately 2,350 tons of coke in 24 hours.

Pig Casting Plant

Any surplus metal above open-hearth requirements is poured over a pig casting machine, which has a capacity of 1,000 tons daily. This equipment is located near the Duplex plant and was built in India from parts furnished by the Pittsburgh Coal & Washer Company. The installation consists of a single two-strand machine 140 feet in length for casting molten blast furnace iron into pigs. Two series of cast iron moulds are arranged on an inclined travelling chain operated by a General Electric 45 h.p. motor on the same principle as a coal bucket inclined elevator, the moulds travelling on wheels over inclined rails. There are 296 moulds in each series, or a total of 592. The blast furnace metal is poured down a Y-shaped trough into the two sets of travelling moulds (which are coated with lime wash), by means of a 75-ton 55-ft. 4-in.-span Alliance ladle crane provided with a 25-ton auxiliary hoist. The pigs, which weigh about 150 lb. each, are cooled by streams of water when nearing the delivery end, where they are emptied out by the automatic overturning of the moulds, and fall down a chute into steel wagons, over which a spray of water is arranged which plays on the pigs to further cool them as they enter the wagons. A concrete-lined tank is located under the pig casting machine, and the water from the sprays is directed into the tank by means of drains. To provide sufficient water pressure for the sprays, a 50 h.p. General Electric motor is provided, with necessary pumps.

Provision is also made for casting the blast furnace metal in sand in cases of emergency, and a light 10-ton crane is used with ball and magnet for breaking sand cast pig iron, slag, etc. There is also another 10-ton crane provided for cleaning up purposes, removing ladle skulls, etc., in the casting bay on the same track as the 75-ton ladle crane.

Blast furnace and Duplex plant transfer ladles are re-lined in the pig casting plant, and for this purpose a ladle repair pit with a capacity for three ladles is provided.

Normally, the major part of the blast furnace product is charged into either the 1,300-ton hot metal mixer at the Duplex plant or the 300-ton mixer at the stationary open-

hearth plant. It is not practicable to cast the output of large blast furnaces in sand beds, and the cast houses for 'C' and 'D' blast furnaces were not so arranged. To take care of the metal from these furnaces and the other blast furnaces as well during week-end shut-downs at the open hearth plants and when the hot metal mixers are filled, a pig casting plant becomes a necessity.

Hot Metal Mixer

The pig iron mixer at the Duplex plant was designed to hold 1,300 tons of molten metal. It is cylindrical in shape, and has a diameter of 20 feet inside the steel casing and an overall length of 41-ft. 6-in. It is supported on concrete piers and rotates on four sets of rollers, there being four cradles attached to the mixer casing which work on the rollers. The mixer bottom and sides to above the normal slag level were originally lined to a thickness of 22½-in. with magnesite bricks, asbestos packing 1½-in. thick being placed between the casing and the first course of brickwork. The mixer ends were also similarly lined, the roof portion being of firebrick 18-in. thick following the same radius as the magnesite lining, leaving thus an air space between the firebrick roof and the steel casing. The interior dimensions inside the brickwork were therefore 16 feet diameter by 37-ft. 6-in. in length.

The thickness of the refractory bottom has been considerably increased since the mixer was first lined, with the result that its maximum capacity is now about 800 tons. The roof portion at present is of 12-in. firebrick.

The mixer is a non-active one and is heated with either coke-oven gas or coal tar, burners being placed at the pouring-out spout and through a port at each end of the vessel.

The mixer is set on a very high level, the mixer house floor being approximately 44 feet above ground level. The mixer house, which is 85 feet wide and 100 feet long, is served by a 100-ton 72-ft.-span Alliance ladle crane, which picks up each blast furnace ladle from its truck, hoists the ladle to a height of more than 50 feet above ground level, and by means of a 25-ton auxiliary hook the ladle is tilted and the contents poured into the mixer. The mixer is operated by means of

two General Electric 100 h.p. motors working in unison, and storage battery power is provided for cases of emergency. The necessary electric control panels are located near the mixer on the mixer floor level. When metal is required for the converters, the mixer is tilted and the required weight of metal poured into a 30-ton ladle mounted on a truck, there being four of these transfer ladles provided. The ladle and truck are supported on a 100-ton weighbridge so that the metal can be weighed as it enters the ladle. The ladle of metal is then propelled by wire-rope haulage, operated by a General Electric 18 h.p. motor, to either of two 25-ton Bessemer converters.

The erection of another hot metal mixer of 800 tons capacity is contemplated, to take care of additional blast-furnace metal and thereby reduce the possibilities of unsaleable metal having to be cast in the pig casting machine.

Bessemer Converters

There are two converters, each of 25 tons capacity, into which the hot metal from the mixer is poured by means of a 17-ton jib crane situated centrally between the vessels so that it is able to serve them both. This crane is electrically operated by one General Electric 45 h.p. motor for hoisting, and one 8 h.p. motor for rotating the jib. By means of air blast ranging from 17 to 25 lb. per square inch, introduced through tuyeres in the converter bottom, the hot metal is blown for a period ranging from about 6 to 15 minutes, according to the requirements of the Duplex open-hearth furnaces, in order to remove the silicon and reduce the percentage of carbon. The converters, each of which can be completely rotated by means of two General Electric 100 h.p. motors working in unison, then tilt their charge into a ladle of 40 or 60 tons capacity mounted on a truck, eleven ladles (six of 40 tons and five of 60 tons capacity) being provided for conveying the blown metal to the Duplex open-hearth furnaces. The contents of the ladle are weighed on a 150-ton weighbridge, after which the ladle is shunted by a 5-ft. 6-in.-gauge steam locomotive into position for being lifted by a 100-ton Alliance ladle crane and carried to the Duplex open-hearth furnaces.

The electric controls for operating the jib crane and the

haulage rope are contained in a small building located between the mixer and the converter on the converter floor level, and in this building is also a Bristol Company (U.S.A.) air-pressure recorder.

The converters, which are 12 ft. 9 in. maximum diameter inside the shell, are lined solely with roughly cut mica schist, which refractory material is found in very large quantities in the vicinity of the works. The schist lining is approximately 20 in. to 24 in. thick, and the jointing is made with a silicious composition consisting of a mixture of clays and ground silica stone, etc., particulars of this mixture being given in Section V of the paper.

The converter bottoms contain 25 tuyeres and are attached to the vessels by means of 12 steel hanger bars and wedges, while the bottom cover plates are fastened with 24 cotter pins and wedges.

Two Yale 2-ton spur-gearred lifting blocks, on a rotating jib, are provided, one near each vessel, for removing the converter bottom plates for examining the tuyeres.

The converter building is 85 feet wide and 200 feet in length, with a platform 20 feet above ground level. The building is on the same floor level as the Duplex open-hearth furnaces platform, at an elevation of 558 feet above sea level.

The first heat was blown in No. 2 converter on February 13th, 1924, and in No. 1 converter on March 13th, 1924.

The blowing pulpit from which the steel blowers operate the converters is situated approximately 70 yards away and directly opposite the vessels, and is adjacent to the blower house. Steam is provided for the steel blower to cool down any metal which he judges to have acquired too high a temperature during blowing.

The main air pipes from the blower house to the converters are situated underground, and a pair of control valves, each manipulated by a 2 h.p. General Electric motor, are located in a pit near the converters.

Blower House

For supplying the necessary air blast to the converters, a separate blowing engine house was erected, containing two General Electric 28,000 cubic feet capacity electrically driven

blowers, one for each converter. These blowers are rated to run at a speed of 3,520 r.p.m., the rated air pressure from the centrifugal compressors being 31.5 lb. per sq. in., while the rated h.p. of the motor is 3,600 and the load 2,700 k.w. The blower house also contains a British-Thomson-Houston 500 k.w. continuous current generator with a 3,000-volt 50-cycle synchronous motor, and all necessary control panels.

A 100 k.w. engine-driven generator was originally installed to serve as a stand-by for furnishing power to the tilting motors at the mixer, converters, and Duplex open-hearth furnaces, in case of an interruption occurring in the electrical service from the main power house. This generator, however, was removed from the blower house a few months ago, as it was found to be unnecessary, and in its place a new General Electric 750 k.w. continuous current generator with a 3,000-volt synchronous motor was installed, the induction motor in connection with the set being of 3,600 h.p.

A Schutte & Koertling oil-cooler is provided in connection with the turbo blowers, and also a De Laval centrifugal oil purifier operated by a 1 h.p. General Electric motor. Two storage tanks for oil are located near the roof of the blower house building.

A Bristol Company (U.S.A.) recorder is fitted in the blower house for supplying a permanent record of the air pressure supplied to the Bessemer converters.

The blower house is served by a 25-ton 44-ft.-span Alliance crane fitted with a 10-ton auxiliary hoist.

Converter Bottom House

The operation of the two Bessemer converters requires the frequent changing and relining of converter bottoms. These are taken off the vessels on hydraulic jack cars, of which there are two in daily use, and shunted by 5-ft. 6-in.-gauge steam locomotive to the bottom house for re-lining. A pit is provided for this purpose, over which the converter bottom is supported. The bottoms, after being relined, are placed on bogies and run on rails into one of eight drying ovens, each oven being designed to hold one bottom. These drying ovens can either

be heated with coke-oven gas or coal, a temperature of about 900°F. (482°C.) being sufficient for drying the bottoms. Each pair of ovens is connected to a chimney-stack 80 feet in height and 3 feet interior diameter, except Nos. 5 to 8, which at present have only one stack between them. Originally six ovens were built, each pair being connected to a stack. Nos. 7 and 8 ovens are the most recent additions and were connected to the existing stack for Nos. 5 and 6 ovens. Space has been left for an ultimate total of ten ovens. After the re-lined bottoms have been thoroughly dried, they are taken on the hydraulic jack cars back to the converter building and placed on the vessels.

The bottom house contains the necessary machinery for preparing the material for re-lining the bottoms, consisting of Allis-Chalmers gyratory crusher, 9 ft. diameter dry and wet pans, all being driven by one 125 h.p. General Electric motor.

The main building consists of a structure 67 feet wide by 216 feet long, and is served by a 25-ton 60-ft.-span Alliance crane provided with a 5-ton auxiliary hoist, and there is a lean-to 20 ft. wide and 154 ft. in length covering the raw material bins, etc., which is served by a 10-ton 20-ft.-span Alliance crane.

Adjacent to the bottom house is a building containing a 12,000 gallons capacity tar fuel storage tank with a pair of steam-driven pumps for supplying tar to the various burners in the Duplex plant, and also to the blooming mill for use at the two bloom reheating furnaces and to the merchant mill for the Morgan continuous heating furnace. The tar in the storage tank is heated by steam, the tank being filled either from tar tanks mounted on bogies, and shunted from the by-product plant after being filled there, or by pipe line from the plate mill storage tanks, which are in turn supplied by pipe line from the coke ovens by-product plant.

For operating the hydraulic jack cars for the converter bottoms, a 500-lb. per sq. in. accumulator with the necessary pumps is provided near the converters.

Duplex Open-Hearth Furnaces

These consist of one 200-ton and one 250-ton-capacity tilting open-hearth furnaces. Each end of the furnace rests

on a reciprocating bed, gear teeth on the cylindrical bottom of the furnace engaging rack teeth on the flat bed. The bed is moved by a worm gear operated by two 100 h.p. General Electric motors, these being connected by a stabilizer to ensure operation in unison. The tilting mechanism is so arranged that the furnace proper rotates about its own centre, thus keeping the ports in line so that the fuel may be burned and the flame kept in the melting chamber even while the furnace is tilted, the gas and air port blocks being stationary. The range of tilting is about 35° on the pouring side of the furnace and about 15° on the charging side.

The furnaces are of large proportions, the dimensions of the hearths being 16 ft. by 42 ft. for 'A' 200-ton furnace, and 16 ft. by 50 ft. for 'B' 250-ton furnace. Both furnaces have an overall length of 92 ft. the extra 8 ft. in the length of 'B' furnace hearth being taken from the length of the port blocks. The overall width of the furnaces is 22 feet.

In building-up the furnace bottoms, one $4\frac{1}{2}$ -in. course of firebricks was first placed upon the bottom plates, and then 4 courses (18 in.) of magnesite bricks were laid upon the firebrick course. Austrian burnt magnesite mixed with basic slag was then spread over the magnesite bricks in thin layers, each layer being heated until it fritted by means of the furnace flame in the usual way, until the hearth was completed. Magnesite bricks are also used for building the charging and tapping side walls and for the melting chamber ends of the gas and air ports, while the roofs are built of locally manufactured silica bricks, the centre portion for a length of 22 ft. for 'A' furnace and 26 ft. for 'B' furnace being constructed of a series of panels and ribs, 4 courses of 12-in. bricks forming a panel and 2 courses of 16-in. bricks forming a rib, while the remaining end portions are built of 12-in. bonded brickwork. The rise from the skew-back to the centre of the roof is 3 ft. 6 in. The furnaces are provided with slag pockets. The regenerator chambers are 30 ft. 0 in. in length and 21 ft. 3 in. in height (from floor to roof), the gas chambers being 8 ft. 9 in. wide and the air chambers 13 ft. 3 in. wide. The regenerators are checkered with 9 in. by $4\frac{1}{2}$ in. by 3 in. firebricks arranged to form a series of 6 in.-square flues, silica bricks being used for the last eight courses, the total height of the built up checker

bricks being 16 feet above floor level, or 11 ft. 4½ in. above the top of the bearer bricks.

The furnaces are equipped with Blaw-Knox ⁽¹⁾ water-cooled doors, frames, ports, charging side walls, 'monkeys', gas and air reversing valves, and also water-cooled joint castings (chills) fitted between the tilting portion of the furnace and the stationary port blocks. The water for cooling is circulated, and a circulation tank is fitted over each furnace. The circulation system reduces the quantity of water about 30 per cent below the amount which would be required with direct feed, and the circulation tank acts as a reservoir in the event of the water supply being accidentally cut off, until either the water feed line is repaired or an emergency connection made with the tank. There are also two return water tanks situated on the ground level under the charging platform, one tank being provided for each furnace. Water for cooling the furnaces is pumped from each of the tanks, 'A' furnace pumps being operated by a 20 h.p. General Electric motor and 'B' furnace pumps by a 25 h.p. General Electric motor, the water pressure being approximately 35 lb. per sq. inch. To keep up the supply of water for the furnace cooling equipment in case of failure of the electrically controlled pumps in the power house, a concrete tank was constructed near the Duplex plant and on a higher level, which will provide water for approximately two hours if necessary, the tank being afterwards refilled by a Curtis steam turbine supplied by the General Electric Company. This turbine is of 130 h.p. and is a 150-lb. per sq. in. non-condensing type, while the pump is a Tan-Gyro rotating one.

The furnaces are provided with five doors on the charging side, but only three of these (Nos. 2 to 4) are used for charging purposes. The doors are electrically operated by 5½ h.p. General Electric motors, and the Knox flue reversing valves, which consist of simple vertical water-cooled dampers operating directly in the flues, are also electrically controlled by a General Electric 25 h.p. motor, the mechanism being so designed that

(1) Particulars of the various Blaw-Knox water-cooled devices are given by Wm. C. Coffin in a paper on "Water-cooled Equipment for Open-Hearth Steel Furnaces" read at the New York meeting of the American Institute of Mining Engineers, February, 1919, and published in the Institute *Bulletin*.

the gas-reversing dampers work in a series ahead of the air-reversing dampers, so that no mixture of gas and air can take place in the flues which might cause an explosion, especially when waste-heat boilers are used. The damper valves are inclined a little in order to ensure close contact between the damper and the seating frame.

The furnaces and valves were originally designed for burning coal tar or gas from the coke-ovens, and tar storage tanks were provided with pumps to force the tar to the burners at the furnaces. As, however, the supply of tar and coke-oven gas was found to be insufficient, two batteries of four mechanically operated Morgan gas producers were installed, one battery of four producers being provided for each open-hearth furnace. The use of tar and coke-oven gas was then discontinued for melting purposes, but tar is still used for heating up the melting chamber and the checkers after a furnace has been shut down for repairs, prior to producer gas being directed into the furnace, thus reducing to a minimum the risk of explosions occurring during the lighting up of the furnace. For heating up the melting chamber, tar burners are placed down the gas ports, and for heating the checkers, burners are introduced through a stopping in each slag pocket bulkhead.

The furnace chimneys are each 7 ft. 9 in. diameter inside the firebrick lining and 190 feet in height above ground level, which is 538 feet above sea level at the bases of the stacks, the ground line level for the Duplex plant being 536 feet above sea level.

The furnace building is very lofty, the eaves being 75 feet above ground level. It is 84 feet wide on the charging side and 72 feet wide on the pouring side (casting house) and is 460 feet in length, and contains about 10,000 tons of steel work. Owing to the large size of the Duplex open-hearth furnaces, the spacing of the centre columns is 115 feet, necessitating very heavy construction, the crane girders between the charging and pouring bays being 15 feet in depth. Sufficient building is provided for another Duplex open-hearth furnace of similar size to the existing ones, the construction of a third furnace being contemplated in the near future. There is also space for three electric furnaces, two of 6 tons and one of 20 tons capacity. A 6-ton electric furnace for melting the ferro-

manganese or spiegel prior to its addition to the open-hearth casting ladle, has been partly erected, but owing to the lack of sufficient electric power to operate the furnace, its installation has not been completed.

The charging platform is 21 feet above ground level (at an elevation of 558 feet) and is equipped with a 3½-ton 25-ft.-span Alliance low-type charging machine for handling the charging boxes containing mill scale, ore, flux, pig iron, or scrap, and also the chutes for pouring the hot metal from the converters into the open-hearth furnaces. There are twelve of these pouring chutes in use, and each is provided with a slot similar to the charging boxes. The charging machine ram fits into this slot and the chute, which is lined with firebrick, is lifted and carried by the ram to one of the furnace doors where it is placed on the platform, the chute being so designed that its base rests on the furnace platform while the chute itself enters the furnace charging door-hole.

A 100-ton 75-ft.-span Alliance ladle crane (of which there are two, one having just recently been erected) picks up the 40- or 60-ton ladle containing the charge of blown metal from the Bessemer converter, the crane track being 58 feet above ground level. The ladle is hoisted and as much slag as possible poured off by tilting the ladle with a 25-ton auxiliary hoist. The ladle of hot metal is then carried to one of the charging doors of the open-hearth furnaces, and the metal is poured into the furnace down one of the chutes previously placed into position by the charging machine.

The metal is then refined by making the necessary additions of mill scale, ore, flux, etc., the phosphorus being almost removed in the process, and the sulphur slightly diminished, after which the metal is tapped and additions made to bring the finished steel to the required composition.

The furnace building is also equipped at the south end with a 15-ton repair trolley running on a 9-ft.-gauge track constructed at right angles to, and extending over, the other crane tracks right across the melting and casting bays. This trolley is used for removing skulls from the pouring chutes, hoisting material on to the furnace platform, repairing overhead cranes, etc.

A slag transfer railway track is provided under the charging platform, this track being a continuation of that passing under the Bessemer converters and used for shunting the truck of blown metal into position for being hoisted by one of the two 100-ton ladle cranes.

The furnace platform is also equipped with a chemical laboratory, in which bath samples and ladle samples are analysed, carbon determinations being made by the volumetric combustion method. A drilling machine is also provided in the laboratory.

'A' furnace was first charged on February 13th, 1923, and 'B' furnace on January 30th, 1924. As the erection of the Bessemer converters was not then completed, both the open-hearth furnaces worked the Talbot process, with charges of 90 per cent hot metal and 10 per cent cold pig and scrap, until February 13th, 1924, when No. 2 converter was put into commission and the Duplex process adopted.

Waste-Heat Boilers

Each furnace was originally connected to a 500 h.p. Wickes vertical waste-heat boiler to generate steam for atomizing the tar at the various burners and to furnish steam for the gas producers. Owing, however, to insufficient heat being obtained from the waste gases to provide the necessary steam required, the flues to the boilers were closed and tar and coke-oven gas burners installed for raising steam. A large induced draught fan driven by a 35-70 h.p. General Electric motor was placed between the boilers and the stack.

In July 1926 two separate Wickes vertical coal-fired boilers, each of 500 h.p. and connected to an independent stack 5 ft. 9 in. diameter inside the firebrick lining and 120 feet in height, were installed near the furnace building. These coal-fired boilers and stack were removed from the discarded Coppée non-recovery coke ovens, and re-erected at the Duplex plant. Each boiler is provided with four fire-holes, and dust and very small coal screened from the gas-producer coal and rejected as unfit for charging into the producers, is used, together with coke breeze, for firing, and is much more economical than coal tar or coke-oven gas. Each fire is provided with two steam jets for blowing and the steam pressure for service to the

Duplex plant is maintained at about 150 lb. per sq. inch. The old waste heat boilers have now been dismantled and re-erected elsewhere.

Gas Producers

These consist of eight Morgan gas machines, built by the International Construction Company. They are arranged in two batteries of four producers each, one battery providing gas for 'A' and the other for 'B' Duplex open-hearth furnace. The producers have an internal diameter of 10 feet and are each capable of gasifying 3,000 lb. of coal per hour (38.2 lb. per sq. ft. and hour), the normal average rate in practice, however, being less than two-thirds of this amount.

The producer body and ashpan are revolved while the water-cooled top remains stationary, but the top of the fuel bed is not agitated. Ash removal is arranged to take place at one and the same time, all around the fuel bed.

The power consumption is very low, being only $\frac{3}{4}$ h.p. for ordinary operation and $1\frac{1}{2}$ h.p. when the plough is operating. The number of revolutions per hour generally varies between 5 and 6, one revolution taking place in about $10\frac{3}{4}$ minutes.

The principle upon which the Morgan gas machine is designed is that gas-making should be carried out with the least disturbance of the fuel bed either manually or mechanically.

The fuel is charged by a water-cooled double chamber drum feed and is levelled during the revolution of the body by a water-cooled U-shaped floating bar, which is fixed in trunnions on the top plate and is provided with a weight of adjustable leverage to enable the pressure of the leveller on the top of the fire to be controlled. The levelling bar extends from the centre of the producer to the wall on one side, thus constantly scraping the surface of the fuel and filling up any holes without unduly turning over the fuel.

The producer body rests on a 3-armed spider carried from the ashpan, which also serves to distribute part of the blast to the fire before it passes to a circumferential air distributor, and a small quantity of blast is also admitted through a central hood. The fire is blown by a steam injector, the average steam pressure being 60 lb. per sq. in. and the consumption of steam about $\frac{1}{6}$ lb. per lb. of coal gasified. The

average saturation temperature of the air and steam is about 58°C.

The ash-removing device consists of a spiral-shaped bar ending in an ash discharge plough. Normally the ash-removing device revolves with the gas producer and ashpan. When it is desired to remove ashes, the plough (with spiral displacer) is stopped and maintained stationary during one complete revolution, when it is again automatically released to revolve with the gas producer. Each producer is cleaned once during every 8-hour shift.

The gas producer plant is also equipped with an electrically operated bucket elevator and belt conveyor for carrying the coal to overhead bunkers from which the producers are charged. The coal is hand unloaded from the wagons and passed through a grid into an underground bunker and directed into buckets on an inclined elevator which deposits the coal into a coal crusher. The inclined elevator is operated by a General Electric 5 h.p. motor and the coal crusher by a 25 h.p. General Electric motor. The coal is then deposited down a chute into the main vertical bucket elevator, which carries the coal to an endless belt conveyor, the coal passing over a revolving grid fitted with bars spaced $\frac{1}{4}$ in. apart, which screens out the very fine coal and deposits it down a chute direct into wagons, to be used for firing the Duplex plant boilers. The main vertical elevator is operated by a 5 h.p. General Electric motor and the endless belt, which conveys the screened coal to the overhead bunkers, by a 10 h.p. General Electric motor. The belt runs through a travelling hopper which can be fixed over any one of the eight bunkers situated directly over the gas producers, thus directing the coal as desired. The ash is deposited down chutes into skips suspended on a runway in an underground tunnel beneath the producers. These skips are fitted with side doors which are lifted, and the ash transferred to another skip working on a steeply inclined hoist operated by a General Electric 20 h.p. motor. At the top of the hoist the skip is automatically overturned and the contents emptied down a chute into wagons. The soot from the dust collectors is also deposited down the chute with the ash.

The average temperature of the hot reaction zone of the producer is 1,150°C. to 1,200°C., and the average temperature

of the gas in the mains from the producers to the furnace flues is 650°C. to 700°C. These gas mains are 6 ft. 9 in. diameter inside the brickwork lining. Burning out is done fortnightly, that is, every alternate week for each battery of producers, and to loosen the soot and facilitate burning out, steam is blown through pipes inserted into the gas mains.

Casting House

The casting bay of the furnace building is 72 feet in width and 460 feet in length and is equipped with two 150-ton 70-ft.-span Alliance ladle cranes for handling the ladles of steel from the furnaces to the ingot moulds at the casting platform. Each crane is fitted with one 40-ton auxiliary hoist for tilting the ladles for pouring out slag, and also one 15-ton auxiliary hoist for light work. These two hoists were provided for manipulating ladles of molten ferro-manganese or spiegel from the 6-ton electric furnace which has not yet been put into commission. It was intended to hoist the ladle of molten alloy with the 40-ton hoist and pour the contents into the casting ladle by means of the 15-ton hoist while the steel was being poured from the tilting open-hearth furnace into the casting ladle suspended in position under the furnace launder by the lifting hooks of the main 150-ton hoist. These ladle-lifting hooks consist of ten pieces of plate about 15 in. wide cut to the required shape and rivetted together. Eight of the plates are $\frac{1}{2}$ in. thick and the outside ones $\frac{3}{4}$ in., making a total thickness of $5\frac{1}{2}$ in. Two 40-ton 70-ft.-span Alliance cranes are also provided for cleaning up the casting house. The crane track is 58 feet above ground level.

Ten casting ladles are in use, each having a capacity of about 110 tons, and each ladle is fitted with one stopper and nozzle.

Ingot are cast in two sizes of moulds only. The moulds are rectangular in shape and are tapered, the interior dimensions of the smaller moulds being approximately $19\frac{1}{2}$ in. by $22\frac{1}{2}$ in. at the top end and 22 in. by 25 in. at the bottom end, and have a capacity of $3\frac{3}{4}$ tons, while the larger moulds are approximately $23\frac{1}{2}$ in. by 28 in. at the top end and 26 in. by 31 in. at the bottom end, and have a capacity of $5\frac{3}{4}$ tons. The walls of the moulds are of an average thickness of 4 in. for the

smaller and 5 in. for the larger size, the weight of the moulds being $3\frac{3}{4}$ tons and $5\frac{1}{4}$ tons respectively. Both classes of moulds are 72 in. in length. Ingots for the old mills are cast in the smaller moulds, and ingots for the new mills in the larger moulds. All ingots are cast narrow end up, the steel being teemed through a $1\frac{3}{4}$ -in.-diameter nozzle direct into the moulds, which are not provided with feeding heads. The ingot moulds are cast in the Tata works iron foundry, and are provided with a pair of lifting lugs at the narrow (top) end for stripping purposes. The moulds are placed on cast iron bottom plates or stools (cast from blast furnace metal in open sand) which rest on ingot cars built by the Birdsboro' Steel Foundry and Machine Company. Each car supports four ingot moulds. After each cast, the cars are shunted to the stripper yard on 36-in.-gauge railway tracks by steam locomotives, of which there are two for casting house use. The casting platform is 9 ft. 3 in. above ground level.

Other usual casting house equipment is provided, including slag pans, rubbish boxes, ladle stands, etc. There are also two 5-ton balls for loosening skulls, breaking up slag, etc., and three hoist grab buckets are used for cleaning up the casting house floor and slag pits. For cooling down ladles for lining repairs, a rotary fan with pipe connections is used, the fan being driven by a General Electric 10 h.p. motor, and there is also a ladle repairing pit with stands for two ladles.

Stripper Yard

The stripper yard is situated in the open a short distance away from the casting house and in the direction of the rolling mills. It is served by a runway supporting a 75-ft.-span Alliance rope-operated crane for stripping the ingots, the maximum stripping pressure exerted by this crane being 150 tons. As the ingots are cast narrow end up, the moulds are lifted off the ingots by means of the lugs, the ingot being pressed against a vertical ram fitted on the crane.

Stock Yard

For the storage of the necessary supply of ore, scale, dolomite, lime, and alloys, etc., for the furnaces, a stock yard is provided which is served by two 10-ton 100-ft.-span Alliance double trolley travelling cranes arranged for handling grab

bucket and electric lifting magnet. A series of five overhead bins are filled from wagons on an elevated 5 ft. 6 in.-gauge railway track or by the travelling cranes. Three of these bins are used for storing calcined lime, one for calcined dolomite and one for mill scale. Here the charging boxes for the Duplex open-hearth furnaces are loaded from the bins or direct from the yard, and are then shunted to the furnace charging floor by steam locomotive on a 36-in.-gauge track over a trestle extending from the stock yard to the furnace platform, a distance of more than half a mile.

Skull Cracker Yard

For the breaking up of large scrap, such as ladle skulls, ingot moulds, bottom plates, etc., a skull cracker yard is provided, with a 25-ton 80-ft.-span Alliance travelling crane on a runway extending the whole length of the yard. One of the bays of this main runway is designed with a high panel carrying a 25-ton 12-ft.-span cross travel pulley. Both crane and trolley are equipped for handling the steel skull cracker ball with magnets.

Calcining Plant

This plant was started in June, 1924, and contains two horizontal rotating calcining kilns for burning raw limestone and dolomite for use at the Duplex open-hearth furnaces. These materials are unloaded from wagons into one or other of two pits. The stone is then taken from the pits by a grab bucket operated by a 10-ton Alliance overhead travelling crane, and hoisted into bunkers from which it is fed into a Kennedy gearless crusher, of which there are two, one for each kiln, each crusher being operated by a 40 h.p. General Electric motor with belt drive. After being crushed, the stone is deposited down chutes into one or other of three pits, from which another 10-ton Alliance overhead crane on a higher level track picks up the crushed stone by means of a grab bucket and charges it into overhead bunkers, of which there are two, one for each kiln. The stone is then fed from the bunkers down a chute through a feeding hopper, which can be regulated, into a revolving screen perforated with 5/16-in.-diameter holes through which the dust passes and falls down another chute into a fourth pit in line with the three previously referred to

which hold the crushed stone. The screen and feeding device are operated by a 10 h.p. General Electric motor.

The material retained by the screen passes down a hopper fitted over the charging end of the calcining kiln, and thereby enters the kiln. The kilns are 8 feet diameter inside the steel casing, which is lined throughout with 9-in. firebrick. The length of the kilns is 135 feet. They are supported on two sets of four rollers erected on piers, and each kiln is rotated at a speed of approximately 36 revolutions per hour by means of a 20-35 h.p. General Electric variable speed motor. The kilns are slightly inclined towards the delivery end, where burners are fitted for burning coke-oven gas and coal tar or crude oil, by which fuels the kilns are heated, both tar, and compressed air for atomizing, being supplied by the plate mill. The pressure of tar at the burners is about 35 lb. per sq. in., of crude oil about 20 lb. per sq. in., and of compressed air about 45 lb. per sq. in. Tar is delivered from the tar storage tanks in the plate mill through pipe lines to the calcining plant by pumps operated by a General Electric 25 h.p. motor in the plate mill, and a 5 h.p. General Electric motor with pumps is used at the calcining plant for forcing the tar to the burners. There is also an auxiliary tar pump operated by a 2 h.p. General Electric motor. From 15 to 16 tons of coal tar are consumed every 24 hours for both kilns, and when crude oil is used, from 16 to 17 tons of this fuel are consumed during the same period. Two small tar storage tanks, each of $2\frac{1}{2}$ tons capacity and heated by steam, are provided and are filled up as required. A higher temperature and a smaller feed is used for burning dolomite than for burning limestone, the average temperatures being about $1,300^{\circ}\text{C.}$ and $1,150^{\circ}\text{C.}$, respectively, dolomite being calcined in No. 1 kiln and limestone in No. 2 kiln.

After passing through the heated zone, the calcined stone falls into a rotary cooling kiln 45 feet long and 6 feet diameter inside the steel casing, which is unlined. For each calcining kiln, there is a cooling kiln, which is rotated at a speed of 4 revolutions per minute by means of a 15 h.p. General Electric motor and is slightly inclined towards the discharging end. At this end of each cooling kiln another screen, perforated with $5/16$ -in.-diameter holes, is fitted and dust is screened into shallow pits from which it is picked up by an inclined conveyor,

operated by a 5 h.p. General Electric motor, which carries the fine discharged material on to a platform, and automatically deposits the dust down chutes into storage bins, the burnt lime and dolomite dust being mixed together and sold for building purposes. The calcined material retained by the screen passes down a chute into buckets on a vertical elevator operated by a 5 h.p. General Electric motor. The elevators carry the material to four overhead bunkers (two for each kiln), from which it is loaded into wagons through hoppers regulated by a chain, down chutes situated over the wagons. The wagons are then shunted by steam locomotive to the stockyard where the calcined material is unloaded into storage bins, from which it is afterwards loaded into charging boxes as required for the Duplex open-hearth furnaces.

The length of time taken for the material to pass through the calcining and cooling kilns is approximately $3\frac{1}{2}$ hours and 7 minutes respectively. The firebrick lining of the calcining kiln undergoes rather rapid corrosion and requires repairing about once a month.

The waste gases from the kilns are carried away by a chimney stack 7 ft. 9 in. diameter inside the firebrick lining and approximately 150 feet in height, which is situated between the two kilns at the charging ends.

The average consumption of calcined lime at the Duplex plant taken over a period of one year was 154.5 lb., and that of calcined dolomite 25 lb., per ton of steel ingots produced, so that, for a production of 30,000 tons of steel ingots per month, about 2,070 tons of lime and 335 tons of dolomite are required.

The average monthly output of each kiln is approximately 2,000 tons of burned lime and 500 tons of double burned dolomite, if each kiln is run separately on limestone and dolomite for a full month, but since the consumption of lime at the Duplex plant is more than six times as much as of dolomite, it is only necessary to use No. 1 kiln for dolomite for 21 days in each month, and it is, therefore, turned on to limestone for the remainder of the month. The output of the two kilns is then approximately 350 tons of calcined dolomite and 2,600 tons of calcined limestone, so that after supplying the requirements of the two Duplex plant open-hearth furnaces,

there is a surplus of over 500 tons of burned lime which is sent to the stationary open-hearth plant.

Repairing Shops

At the south end of the furnace building are electrical, fitting, and smithing departments, where various repair jobs are executed, and here also are situated electrical and mechanical stores, and an air compressor, driven by a General Electric 80 h.p. motor, capable of supplying air at a pressure of 80 lb. per sq. in. for rivetting and other purposes.

Steel Foundry

Provision is being made at the south end of the Duplex furnace building for making small steel castings, and a core drying stove heated by coke-oven gas has been erected there.

Rolling Stock

For the necessary transport of material, three narrow-gauge (3 ft. 0 in.) and two broad-gauge (5 ft. 6 in.) steam locomotives are constantly in attendance at the Duplex plant. Two of the narrow-gauge locomotives are solely engaged in shunting ingots and moulds, and only travel over specially laid narrow-gauge tracks extending from the casting house through the stripper yard to the blooming mill soaking pits. The other narrow-gauge locomotive is solely employed in transporting material required for the Duplex open-hearth furnaces over the trestle extending from the stockyard to the open-hearth platform. One of the broad-gauge locomotives is occupied in shunting ladles of blown metal into position for being lifted off their trucks by the two 100-ton ladle cranes serving the furnaces, and re-shunting empty ladles back to the converters, while the other broad-gauge locomotive carries out general transport work, such as shunting the hydraulic jack cars and converter bottoms to and from the bottom house, placing wagons in various parts of the Duplex plant for loading up slag and rubbish, and the conveying of slag to the dump, etc. In addition, a 30-ton steam jib crane is employed for dumping slag, cleaning up scrap, and for various other purposes.

SECTION IV. RAW AND MANUFACTURED MATERIALS CONSUMED IN THE DUPLEX PROCESS

The raw materials consumed at the Duplex plant include

iron and manganese ores, limestone, dolomite, magnesite, chromite, fluorspar, sand, silicious stones and clays, and coal; while the manufactured materials consist of refractory bricks, pig iron, ferro-alloys, coke, coal tar and gaseous fuels, and also mill scale.

Iron Ore

Hematite ore is obtained from three mines in the State of Mayurbhanj, which is more than 4,200 square miles in extent and is one of the tributary states of Orissa.

(a) Gurumahisani:

This is a hill mass with three prominent peaks, the highest rising to an elevation of 3,000 feet above sea level. Here lie 750 to 800 acres of rich 'ore-float', *i.e.*, ore lying loose on the surface, which requires no mining and is simply picked up by unskilled labour. It is calculated that there are more than 15 million tons of ore in this property, which is situated 40 miles south of the works site. The ore beds consist of intensely metamorphosed ancient surface flows. The ore forms a solid cap on the top of the mountains and covers the slopes in the form of large and small stones and float varying in thickness from a few inches to about twenty feet. Up to date, only the float ore which has broken away from the main deposits has been gathered, and no underground work has yet been found necessary. The ore deposits of Gurumahisani occur in three parallel and separate leads, which are 7,000 ft., 5,500 ft., and 3,000 ft., respectively, in length, and they range in width from 300 feet up to 700 feet or more. The ore is mined by open cuts, the breasts advancing along ridges in terraces or benches, with gravity inclines to lower the product to the bottom of the hill, where it meets a broad-gauge railway. The following are average analyses of Gurumahisani solid ore and 'ore-float':

	Solid ore	Ore-float
Fe.....	64.33	61.65
P.....	0.075	0.064
S.....	0.021	0.025
Mn.....	0.44	0.50
SiO ₂	1.64	2.47
Al ₂ O ₃	3.83	3.60

(b) Sulaipat:

An ore deposit situated just west of the Khorkai river, where the latter breaks through the Sulaipat-Badampahar range. This deposit is located 46 miles south of the Tata works, the Gurumahisani hill lying 12 miles to the N.N.E. The Sulaipat peak rises to a height of 2,535 feet. The ore body occurs as a single great lens covering a superficial area of some 300,000 or more square feet. There are, besides, two smaller outliers, and about 165 acres of rich float ore. The immediate associates of the ore are banded quartz-iron-ore rock, and a dense blackish quartzite, the latter being especially abundant. The low-lying country to the northwest is occupied by granite. The following are average analyses of Sulaipat ore:

	Solid ore	Ore-float
Fe.....	67.86	66.79
P.....	0.039	0.065
S.....	trace	0.020
Mn.....	0.28	0.26
SiO ₂	1.42	1.62
Al ₂ O ₃	1.77	1.63

Situated about one mile to the southwest of the Sulaipat peak, and only slightly lower in height, is the Okampad peak, where there is a further deposit of very rich ore, an average of several samples giving the following analysis:

Fe	P	S	Mn	SiO ₂	Al ₂ O ₃
67.65	0.043	0.012	0.30	1.58	2.02

A 13- to 15-mile extension of the Gurumahisani railway will tap the Okampad deposit when the time comes for its development.

(c) Badampahar:

A hill 2,706 feet high in the Sulaipat-Badampahar range, situated 8½ miles southwest of Okampad, and 54 miles south of the Tata Works site. Here also a single great lens of ore, approximately 3,000 ft. in length and 500 ft. in breadth, with many smaller outliers, occupies the crest of the range, masses of rich float ore extending for several hundred feet downwards. The immediate associates of the ore are again banded quartzites

and quartz-iron-ore rocks, with abundant rather basic holocrystalline rocks, a variety of charnockite. Here again, the lower ground to the northwest is completely occupied by granite. Average analyses of Badampahar solid ore and 'ore-float' are as follows:

	Solid ore	Ore-float
Fe.....	59.53	58.33
P.....	0.090	0.093
S.....	0.015	0.020
Mn.....	0.79	0.64
SiO ₂	2.58	2.93
Al ₂ O ₃	3.84	4.57

The Tata Company also owns other deposits of iron ore which are retained as reserve sources of supply. These include the Dhulli and Rajhara ore beds, which are richer in iron and much lower in phosphorus than Gurumahisani ore, but are situated in a more isolated position. Recent prospecting operations have determined the existence of more than a dozen other deposits of high-grade ore in less accessible parts of the Mayurbhanj State, while in Singhbhum a workable deposit has been located at Noamundi, from which a high-grade ore will shortly be obtained for works' use, the haulage distance being about 80 miles.

The ore deposits have all been found to take the form of roughly lenticular leads or bodies of hematite, with small proportions of magnetite, in close association with the granite on the one hand and granulitic rocks (or charnockites) on the other. In still more intimate association with the ores are masses of dense quartz rocks, frequently banded, and banded quartz-iron-ore rocks. There also exists a net-work of basic dykes, which cut the granite and apparently cut the iron ores and charnockites. It appears that the ore bodies occur at or near the contacts between the granite masses and the charnockites. The relative ages of these rocks have not yet been determined.

Iron ore from each of these mines is used in the blast furnaces for the production of pig iron for sale and for steel manufacture, but only the Sulaipat ore, which is the richest in

iron, is used in the Duplex open-hearth furnaces. The average consumption of iron ore at the blast furnaces is about 3,500 lb. per ton of pig iron produced. The consumption of iron ore in the Duplex open-hearth furnaces is very low and averages only $26\frac{1}{2}$ lb. per ton of ingots produced, as it is only employed occasionally when it is necessary to speed up the oxidation of carbon from the furnace bath.

About half a million tons of iron ore is obtained annually from the Tata Company's mines. This constitutes about 62 per cent of India's total iron ore production.

Mill-Scale

Clean scale from the rolling mills is used in the Duplex open-hearth furnaces, an average analysis of this material being as follows:

SiO ₂	FeO	Fe ₂ O ₃	Total Fe
trace	59.50	36.75	72.00

Oxide of iron which is ejected in considerable quantities from the Bessemer converters in the form of small globules or shot during blowing, and is deposited on the ground and steadily accumulates into heaps, is periodically collected and used, mixed with scale, in the open-hearth furnaces. This oxide has also been used for mixing with local calcined magnesite for repairing the tapping side walls of the furnaces. These globules have the following average composition:

SiO ₂	MnO	P ₂ O ₅	FeO	Fe ₂ O ₃	Total Fe
1.24	0.77	0.439	31.83	61.91	68.09

The average consumption of scale in the Duplex open-hearth furnaces is approximately 65 lb. per ton of ingots produced.

Manganese Ore

This is obtained from the Central Provinces, some 500 miles from Jamshedpur. The chief mine is at Balaghat, 32 miles from the Bengal-Nagpur railway line, with which it is connected by a branch line. The production of manganese ore is much greater than the amount required at the Tata Iron & Steel Works, which is about 7,000 tons annually, so that the remainder of the ore produced is available for export. The following is an average analysis:

Mn	Fe	P	SiO ₂	Insoluble residue
51.6	6.9	0.09	6.5	8.2

Manganese ore is used in the blast furnaces when making pig iron, in order to keep up the percentage of manganese in the iron to the required amount, with the exception of the furnace (at present 'D') making pig iron for the sole use of the Duplex plant, the iron from this furnace containing only the residual manganese from the iron ore charged. Manganese ore is also used for the manufacture of ferro-manganese and spiegel, a blast furnace which will shortly be requiring a new lining being used for this purpose owing to the more rapid corrosion of the refractory lining which takes place during the manufacture of this alloy in comparison with pig iron.

Manganese ore is also occasionally used in the Duplex open-hearth furnaces, firstly, for the purpose of thinning the slag and making it more mobile in the furnace, and secondly, for the purpose of eliminating sulphur to some extent from the furnace bath when the percentage of this element is likely to be high owing to a high sulphur content of the pig iron from the blast furnaces. The use of manganese ore for the removal of sulphur from the open-hearth bath is discussed in Section V (page 415). The amount of manganese ore used at the Duplex plant is, however, very small and averages less than 1 lb. per ton of steel ingots produced.

Limestone and Dolomite

The Tata Company has a limestone quarry at Jukehi, a station on the East Indian railway near Katni in the Central Provinces, about 500 miles from the works site, and from this source the limestone mostly used as flux in the blast furnaces and Duplex open-hearth furnaces is obtained. Limestone is also obtained from Birmitrapur and Bisra in the Bilaspur district, 250 miles to the west of Jamshedpur. The following are average analyses of raw limestone:

	Jukehi	Birmitrapur	Bisra
CaO.....	51.60	50.80	49.45
MgO.....	1.90	3.18	3.70
Fe ₂ O ₃	0.96	0.56	0.97
Al ₂ O ₃	0.80	0.52	0.75
SiO ₂	3.18	2.16	3.42
Loss on ignition.....	41.17	42.80	41.38

The raw limestone is used as a flux in the blast furnaces which are making foundry irons and ferro-manganese, the limestone being crushed to pass through a 5-in.-diameter ring, whereas the stone is burned at a temperature of about $1,150^{\circ}\text{C}$. in the calcining kilns (described in Section III) before being used in the Duplex open-hearth furnaces. In table II average analyses of calcined limestone, together with the average yield, are given.

Table II.—Average analyses and yields of burned lime from calcining kilns

Deposit:		Jukehi	Birmitrapur	Bisra
Analysis of burned lime	CaO	80.70	78.15	78.50
	MgO	3.40	3.62	4.45
	Fe ₂ O ₃	1.14	1.03	1.43
	Al ₂ O ₃	0.86	1.08	1.37
	SiO ₂	3.60	3.97	4.16
	Loss on ignition.	10.50	11.84	10.52
Stone dust from crushing, not passed through kiln.		15.0%	18.0 %	18.0 %
Total yield of burned lime, including lime dust.		47.75%	40.5 %	41.0 %
Lime dust passing through cooler screen.		1.25%	6.5 %	8.0 %
Actual yield of burned lime used for open-hearth furnaces.		46.5%	34.0 %	33.0 %

The best results are thus obtained from Jukehi limestone, the average lime yield being 13 per cent greater than from Birmitrapur and Bisra limestone, while the percentage of discarded lime dust produced is considerably less. As the analyses of raw and calcined stone from both these deposits are very similar, the inferiority of Birmitrapur and Bisra limestone for calcination must be due to its different physical properties. The lime dust produced has to be discarded owing to its use in the open-hearth furnace having an injurious effect on the furnace checkers by being carried into the regenerator chambers with the waste gases.

The use of sufficient lime in the basic open-hearth furnace is essential for the successful dephosphorization of the metal, and the average amount of burned lime consumed in the

Duplex open-hearth furnaces is 154.5 lb. per ton of steel ingots produced.

Dolomite is obtained from Panposh and from near Kansbahal in the Gangpur State (Bihar and Orissa), 106 and 120 miles, respectively, west of Tatanagar on the main line of the Bengal-Nagpur railway; and also from Kulunga in Mysore, 1,329 miles to the south of the works site. The following is an average analysis of the raw dolomite stone from various deposits:

CaO	MgO	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	Loss on ignition
29.78	20.48	0.77	0.41	2.50	46.00

Raw dolomite is used as a flux in the blast furnaces which are making pig iron for the stationary and Duplex open-hearth furnaces, the dolomite stone being crushed to pass through a 5-in.-diameter ring. The average consumption of raw dolomite in the blast furnaces is about 1,250 lb. per ton of pig iron produced.

Dolomite is also employed for repairing the hearths of the Duplex open-hearth furnaces, and for this purpose it is previously burned in the calcining kiln. The average consumption of calcined dolomite for furnace hearth repairs is approximately 23.5 lb. per ton of steel ingots produced, and the following is an average analysis, together with the average yield:

Table III.—Average analysis and yield of burned dolomite from calcining kilns

Analysis of burned dolomite	CaO	53.00%
	MgO	37.25%
	Fe ₂ O ₃	1.06%
	Al ₂ O ₃	0.86%
	SiO ₂	1.80%
	Loss on ignition	5.75%
Stone dust from crushing, not passed through kiln		18.0 %
Total yield of burned dolomite, including dolomite dust		20.0 %
Dolomite dust passed through cooler screen		3.75%
Actual yield of burned dolomite used for open-hearth furnaces		16.25%

The yield of burned dolomite from Indian stone is therefore very low from the rotary calcining kiln, for double this yield

is obtained from the same stone in the vertical kilns used for calcining dolomite for the stationary open-hearth furnaces. Dolomite from the vertical kilns, however, does not stand so well in the open-hearth, owing to impurities such as silica entering the dolomite from the coke used as fuel.

Dolomite stone is fed into the calcining kiln at a much slower rate than limestone (ratio about 3 to 5), and a higher temperature is employed for the former, *viz.*, 1,300°C.

The calcined dolomite dust is also discarded, and is mixed with the discarded lime dust and sold for building purposes, while the rejected stone dust from crushing is used for filling purposes.

The limestone and dolomite deposits are of pre-Cambrian age. About 25 per cent of the total limestone and dolomite production of India is obtained from the Tata Company's quarries, which produce nearly $\frac{1}{2}$ million tons annually.

Magnesite

Magnesite for building the Duplex open-hearth furnace hearths was imported from Austria, and although domestic magnesite is obtainable in considerable quantities, it is so inferior to the Austrian that the latter is still used for furnace bottom repairs. The following are average analyses of raw Austrian magnesite and the calcined product imported:

	Raw Austrian magnesite	Calcined Austrian magnesite
MgO.....	41.22	87.33
CaO.....	2.52	1.70
MnO.....	0.05	....
FeO.....	0.65	....
Fe ₂ O ₃	0.56	8.57
Al ₂ O ₃	3.17	1.33
SiO ₂	2.25	0.70
Loss on ignition.....	49.08	0.30

For use in the open-hearth furnace, the calcined Austrian magnesite is mixed with finely ground basic slag in the proportion of 4 parts magnesite to 1 part basic slag.

Domestic magnesite is obtained from Kadakola and Kulunga in Mysore, 1,329 miles to the south of Jamshedpur. Table IV gives average analyses of the raw and calcined material, with the average yield from the calcining kiln:

Table IV.—Average analyses of raw and calcined Indian (Kulunga) magnesite, and yield from calcining kiln

		Raw Indian magnesite	Calcined Indian magnesite
Analysis	MgO	45.08	85.13
	CaO	2.03	5.85
	Fe ₂ O ₃	0.73	3.67
	Al ₂ O ₃	2.28	0.42
	SiO ₂	1.80	4.48
	Loss on ignition	50.27	0.22
Stone dust from crushing not passed through kiln.			18.0%
Total yield of burned magnesite, including dust.			38.5%
Magnesite dust passing through cooler screen . . .			5.0%
Actual yield of burned magnesite used for open-hearth furnaces.			33.5%

Experiments are being conducted with a view to finding a satisfactory mixture which will cause the domestic magnesite to sinter satisfactorily. Mill scale and crushed iron ore, mixed with Indian magnesite in varying proportions, have been tried, but the best results have been obtained by mixing 10 per cent of the oxide of iron globules ejected from the Bessemer converters during the blowing of metal. An analysis of these globules has been given above (page 334).

The oxide is mixed with the raw magnesite before passing into the rotary calcining kiln, and the calcined product is mixed with tar before being used in the open-hearth furnaces, where it has been successfully employed for repairing the tapping side walls. This mixture can be fritted in about 1½ hours, or half the time required for Austrian magnesite (mixed with 20 per cent basic slag). However, as stated previously, the latter is still employed for bottom repairs, as it is much more reliable. For the calcination of raw magnesite a very slow feed and a very high temperature are essential. The temperature required is higher than for either limestone or dolomite, and is at least 1,600°C.

The consumption of burned magnesite averages approximately 4.7 lb. per ton of steel ingots produced.

Magnesite Bricks

The production of Indian magnesite bricks in large quantities is not yet firmly established, but steady progress has been made in this direction at the Kumardhubi Fireclay & Silica Works of Messrs. Bird & Co. This Company has made magnesite bricks from the Tata Company's Mysore magnesite, and they compare very favourably in service with Austrian magnesite bricks; but at present the production is very small and insufficient to meet the Tata Company's requirements so that the Company is not yet independent of foreign supplies and is still obliged to import these bricks from Austria.

The Tata Company has also experimented with the manufacture of magnesite and magnesite-chromite bricks at Jamshedpur, where a small kiln has been constructed near the Subarnarekha river. Both kinds of bricks have been successfully made and behave very satisfactorily in the open-hearth furnaces, and the results of the experiments are such that it is anticipated that the manufacture of these bricks will be carried out on a sufficiently large scale by the Tata Company in the near future to fully supply the requirements of the open-hearth furnaces. The following are representative analyses of Indian and imported Austrian magnesite bricks:

	Austrian magnesite brick	Kumardhubi magnesite brick	Tata magnesite brick	Tata magnesite- chromite brick
MgO.....	87.80	85.15	84.46	62.88
CaO.....	2.50	6.02	5.81	6.25
Fe ₂ O ₃	5.43	4.17	3.02	10.01
Al ₂ O ₃	3.77	1.03	2.14	4.36
Cr ₂ O ₃.....	.....	.....	.....	11.99
SiO ₂	0.60	3.39	4.38	4.56
Loss on ignition.....	nil	0.18	0.30	0.22

Magnesite bricks are used for shaping the bottoms of the Duplex plant open-hearth furnaces, and also for the

charging and tapping side walls and the melting chamber ends of the gas and air ports.

Chromite

Chromite is used as a neutral parting layer between the basic and acid refractories in the Duplex open-hearth furnaces, and is obtained from Chaibasa in the Chota-Nagpur district, about 42 miles from Jamshedpur, being close to the iron-ore deposits. This deposit was only discovered a few years ago. Other discoveries have been made in Mysore State, the most productive mine being that of Bairapur, from which over 30,000 tons of chromite, averaging about 50 per cent Cr_2O_3 , are obtained annually. Chromite has also been discovered in Baluchistan. The following are representative analyses:

	Chaibasa chromite	Bairapur chromite
Cr_2O_3	47.64	51.10
Al_2O_3	8.95	7.60
Fe_2O_3	0.84	1.03
FeO	22.19	21.44
MnO	0.23	0.30
CaO	0.95	0.60
MgO	12.67	12.10
SiO_2	4.78	4.50
SO_3	0.06	0.05
Moisture.....	1.50	1.30

Chromite or chrome ore is finely ground for use in the open-hearth furnaces.

Chrome Bricks

Experiments in the manufacture of chrome bricks from domestic chromite are now being made by the Tata Company at Jamshedpur, in the small kiln constructed near the Subarnarekha river. A considerable number of these bricks have been manufactured and are being used for lining the blooming mill soaking pits, where they are behaving quite satisfactorily. The following is a representative analysis of locally manufactured chrome bricks:

Cr_2O_3	Al_2O_3	FeO	CaO	MgO	SiO_2	Loss on ignition
44.05	11.74	21.93	0.40	12.10	9.28	0.96

Fluorspar

Although, in many parts of the world, fluorspar is a fairly common gangue mineral in metalliferous veins, particularly those carrying lead and zinc ores, no workable deposits of this mineral have yet been discovered in India.

The small quantities of fluorspar which are required for occasional use in the basic open-hearth furnaces are therefore imported from Great Britain. Chemically, fluorspar is a fluoride of calcium (CaF_2), containing when pure 51.28 per cent calcium and 48.72 per cent fluorine. The following is an average analysis of the imported fluorspar used in the Duplex open-hearth furnaces:

CaF_2	CaCO_3	MgCO_3	MnO	Fe_2O_3	Al_2O_3	SiO_2
83.15	2.97	1.74	0.12	2.28	2.32	7.20

The consumption of fluorspar is about $3\frac{3}{4}$ lb. per ton of steel ingots produced. It is usually mixed with 50 per cent mill scale, and the mixture employed in the open-hearth for thinning out the slag when necessary, and for aiding the elimination of sulphur from the metal.

Sand

The sand used for the pig beds at the blast furnaces and pig casting plant, and also in the Duplex plant casting house for the bottoms of slag holes, and for various other purposes, is obtained locally, from the bed of the Subarnarekha river, and a special narrow-gauge (2 ft. 0 in.) track has been laid from the river bank to the blast furnaces for the transport of this river sand.

Mica Schist

Mica schist, or mica slate, is found in abundance in the neighbourhood of Jamshedpur, and the Tata iron and steel works are everywhere underlain by this refractory material, which afforded very good and cheap foundations for the works plant. Mica schist is used for the lining of the Bessemer converters, and is also crushed for mixing with other silicious materials for making up the converter bottoms and for converter patching mud. The following is a typical analysis:

SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Total alkalies	Loss on ignition
91.32	0.29	6.43	0.10	0.14	0.10	0.90

Ganister

This argillaceous sandstone is also found locally in the Carboniferous series, and is used for converter bottoms and patching mud, being crushed and mixed with other silicious materials. A representative analysis is as follows:

SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Total alkalis	Loss on ignition
95.20	1.03	2.25	0.85	trace	0.10	0.55

Fireclays

White, yellow, red, grey, and black clays are found in abundance in India, but unfortunately, although the deposits are spread over a large area, they are usually too remote from places where the clay can be of practical use. The chief sources of supply are the Bengal coalfields and deposits in the Central Provinces near Jubbulpore. Bengal fireclay is obtained chiefly from the Barakar and Raneegunge districts in the coalfields and generally occurs in shallow surface workings. White fireclay, to be used as jointing material for laying firebricks, is supplied to the Tata works ready ground by local refractory brick manufacturers, while white clay to be used along with other argillaceous material for lining the converter bottoms and for converter patching mud is supplied in lump form and is ground in the Duplex plant bottom house already described in Section III. Yellow and red clays occur abundantly in the neighbourhood of the works, and both these clays (red clay in particular) are made plastic with water and employed for sealing manhole covers in gas mains and flues, and for the prevention of a 'burst-out' of molten steel from under the ingot moulds during casting. For the latter purpose, the moistened clay is packed round the mould bottoms on the bottom plates or stools. It is also used as a slurry inside the moulds, being poured on the bottom plates and allowed to dry before casting. As both the ingot moulds and bottom plates are usually hot from the previous cast when the slurry is poured in, it quickly dries. Grey and black fireclays are ground in the Duplex plant bottom house, and used with other silicious material for converter bottoms and patching mud. Typical analyses are given in table V.

Table V.—Analyses of Indian Fireclays

	White		Yellow	Red	Grey	Black
	Lump fireclay for con- verter bottoms	Special 'Rajhara' ground fireclay for brick laying				
SiO ₂	58.80	62.12	54.36	47.78	54.40	53.36
Fe ₂ O ₃	1.85	1.86	4.29	7.24	2.09	2.60
Al ₂ O ₃	28.05	22.80	27.35	25.82	30.57	28.78
TiO ₂	1.50	1.36	1.56	0.76	1.38	1.02
MnO.....	Nil	trace	Nil	0.45	Nil	trace
CaO.....	0.70	1.55	0.90	2.02	0.20	0.55
MgO.....	trace	0.42	trace	trace	0.55	trace
Total						
alkalies...	trace	0.34	trace	0.80	1.59	1.74
Loss on ignition...	9.00	9.42	11.40	15.24	9.10	11.90

Silica Clay

The silica clay used by the bricklayers as jointing material for laying silica bricks is obtained by grinding and screening local ganister and other silicious material in the Tata works. It has the following average composition:

SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	Loss on ignition
88.00	1.43	4.93	2.10

Silica Bricks

Raw materials for practically all the refractory products required in the iron and steel industry are abundant in India, but until recent years silica bricks have had to be imported. Now, however, the Kumardhubi Fireclay & Silica Works of Messrs. Bird & Company, near Barakar, East Indian railway, supply the Tata Company with silica bricks which compare very favourably with those hitherto imported. The following is a typical analysis of locally manufactured silica bricks:

SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Total alkalies	Loss on ignition
92.64	0.57	1.23	1.90	1.03	0.24	1.50

Firebricks

These were formerly imported, but are now supplied by several Indian manufacturers and are of good quality. Representative analyses are given in table VI:

Table VI.—Analyses of Indian firebricks

	Bird & Co. Kumardhubi Fireclay & Silica Works		Burn & Co., 'The Potte- ries', Ranee- gunge	The Bengal Firebrick Co., Kulti	The Bihar Firebrick Co.	The 'Reliance' Firebrick Co., Chanch (Andrew Yule & Co.)	
	Ordinary firebricks	Tiles for converter bottoms				Ordinary firebricks	Tiles for converter bottoms
SiO ₂	67.48	63.42	60.86	39.25	59.16	62.60	59.76
Fe ₂ O ₃	2.14	1.95	2.53	2.88	2.78	2.00	2.14
Al ₂ O ₃	28.59	32.38	32.94	34.63	34.18	32.84	36.54
TiO ₂	0.33	0.62	1.08	0.85	1.04	1.16	0.80
MnO.....	trace	nil	0.15	0.10	trace	trace	trace
CaO.....	0.80	0.88	1.04	0.97	1.32	0.45	0.70
MgO.....	0.36	0.30	0.47	0.28	0.37	trace	0.23
Total alkalies.....	0.18	0.27	0.35	0.67	0.71	0.50	trace
Loss on ignition.....	0.18	0.22	0.30	0.44	0.38	0.40	nil

Fireclay Stopper Sleeves, Stopper ends, Nozzles and Well Bricks for Ladles

These are manufactured locally and are of fairly good quality, being supplied by the Kumardhubi Fireclay & Silica Works of Messrs. Bird & Co.; 'The Potteries', Raneegunge, of Messrs. Burn & Co.; and the 'Reliance' Firebrick Co., Chanch, near Dhanbad, of Messrs. Andrew Yule & Co. The compositions of the various makes are very similar, average analyses being given in table VII:

Table VII.—Average analyses of Indian stopper sleeves, stopper ends, nozzles and well bricks for casting ladles

	Ladle stopper sleeves	Ladle stopper ends	Ladle nozzles	Ladle bottom well bricks
SiO ₂	58.88	59.44	58.96	63.48
Fe ₂ O ₃	4.48	4.77	5.86	2.00
Al ₂ O ₃	32.35	32.02	30.66	31.20
TiO ₂	0.89	0.66	0.70	0.80
MnO.....	0.62	0.45	0.77	0.30
CaO.....	1.44	1.22	1.70	0.80
MgO.....	0.18	0.20	trace	0.43
Total alkalies.....	0.57	0.58	0.70	0.36
Loss on ignition.....	0.50	0.44	0.52	0.38

Converter Tuyeres

About two-thirds of the tuyeres used for the converter bottoms are imported from America and the remainder are manufactured in India by Messrs. Burn & Co., 'The Potteries', Raneegunge; the 'Reliance' Firebrick Company, Chanch, (Messrs. Andrew Yule & Co.); the Kumardhubi Fireclay & Silica Works, *via* Barakar, East Indian railway (Messrs. Bird & Co.); and by the Bengal Firebrick Company, Kulti, East Indian railway. The tuyeres supplied by these manufacturers are moderately good, but do not stand up so well in practice as the American 'Climax' tuyeres imported, the latter yielding about 30 per cent better results. Experiments are being

constantly made by each manufacturer to improve the quality of the Indian tuyeres so that they will compare more favourably with those imported, but while a marked improvement has been effected (especially by Messrs. Burn & Co.), the American tuyeres are still superior, and on account of this, two converter bottoms are made with American tuyeres to each one with Indian tuyeres; for if all the bottoms were made with the latter tuyeres, they would have to be changed much more frequently, and it would be impossible to reline and dry the bottoms without causing considerable delays in blowing.

The tuyeres used are 34-in. in length, 6-in. in diameter for a length of 31 in., and taper to 7-in. diameter in the last 3 in. (the neck). Each tuyere is perforated with ten holes of $\frac{5}{8}$ -in. diameter. Twenty-five tuyeres are used for each converter bottom. From three to five tuyeres are usually blanked off on each newly-lined bottom before commencing to blow, so that there is no likelihood of molten metal passing through tuyere holes while the vessel is in a horizontal position for receiving the charge, the blanked off tuyeres being those likely to come below the surface level of the molten metal. Other tuyeres are blanked off as required, usually owing to one or more of them having fused more rapidly than the others. During each blow gradual destruction of the bottom lining takes place, and the tuyeres become steadily reduced in length. As soon as they are found to be only 13-in. long, the converter bottom is taken off the vessel for relining, there being then only 6 in. of clay left to protect the tuyere plates from the metal. By the time the bottom is condemned, from 6 to 12 tuyeres will have been blanked off, the American tuyeres averaging 7 to 8 blanks and the Indian 10; and whereas converter bottoms made with the former tuyeres usually withstand 20 or more blows before the converter bottom plate has to be removed to blank off a defective tuyere, the plate has to be frequently removed for this purpose after about the first seven or eight blows with bottoms made up with Indian tuyeres.

In table VIII a comparison of the average results obtained from Indian and American tuyeres over a period of three months is given:

Table VIII.—Average life of American and Indian tuyeres

Make	Average No. of blows on con- verter bottom	Average time of blow, in minutes	Average total blowing time, in minutes	Average weight of mixer metal blown, in tons	Average total weight of mixer metal blown, in tons
American 'Climax'.....	33	12.6	416	22.0	726.0
Indian { Burn & Co.....	27	11.7	316	22.5	607.5
{ 'Reliance'.....	24	12.2	293	22.25	534.0
{ Kumardhubi.....	20	12.0	240	22.0	440.0
{ Bengal Firebrick Co..	15	12.4	187	21.75	326.25

In table IX average analyses of the various makes of tuyeres are given, and it will be observed that the main difference between the analyses of the American and Indian tuyeres is the lower percentage of silica and higher percentage of alumina present in the former, while the percentage of alkalis is greater:

Table IX.—Average analyses of American and Indian tuyeres

	American 'Climax'	Indian			
		Burn & Co.	'Reliance' Andrew Yule & Co.	Kumar- dhubi, Bird & Co.	Bengal Fire- brick Co.
SiO ₂	52.36	60.28	58.16	61.92	60.64
Fe ₂ O ₃	3.00	2.57	2.97	1.87	1.82
Al ₂ O ₃	40.36	31.69	35.57	33.33	33.98
TiO ₂	0.96	2.68	1.02	0.42	1.38
MnO.....	trace	trace	0.46	Nil	0.15
CaO.....	0.85	1.10	1.15	0.95	0.70
MgO.....	0.80	0.58	0.29	0.35	0.25
Total alkalis.....	1.02	0.46	trace	0.43	0.43
Loss on ignition.....	0.36	0.56	0.20	0.56	0.42

Coal

There is no lack of steam coal nor of gas coal in India but the quality is below that of average British coal. Good coking coal, however, has not yet been found in great quantities, although there is an abundance of inferior coking coal. A moderately good coking coal is obtained from the Jherria coalfield in Bihar and Orissa, about 120 miles north of Jamshedpur. It occurs in beds of the Barakar stage in the Damuda series of the Lower Gondwana system, corresponding approximately with the Lower Permian.

Gas coals are obtained from the Raneegunge coalfield in Bengal, which lies to the east of the Jherria field, and is a little higher in the Damuda series. The haulage distance to the works' site is 130 to 146 miles.

Both these coalfields are served by the East Indian railway. The coal is brought to Adra, thence to Sini Junction, and Tatanagar on the Bengal-Nagpur railway, and from there by the branch line to the works at Jamshedpur.

Out of approximately $1\frac{1}{2}$ million tons of coal consumed annually at the Tata works, about $\frac{1}{2}$ million tons are obtained from the Company's mines; but the greater part of the gas coal supplied to the Duplex plant for gasification in the Morgan gas producers for the open-hearth furnaces, is obtained from the collieries of Messrs. Andrew Yule & Co., including Parbelia, Seebpore, Sodepur, Seetulpore, Damodarpur, Dishergarh, etc.

The coal obtained in India is low in sulphur, being usually below 0.7 per cent, but it has a much higher ash content than good English or American coals, containing generally from 12 per cent to over 16 per cent ash. It has not yet been found possible to reduce the ash appreciably by washing, and it is therefore difficult to keep the ash in the coke product below 20 per cent. Indian coal has also a high phosphorus content, and the coke produced furnishes the greater part of the 0.3 to 0.4 per cent phosphorus usually present in the pig iron made in the blast furnaces.

The percentage of coal dust and very small coal in the gas coals supplied to the Duplex plant is usually very high, and averages about 15 per cent, so that it is very difficult to work the gas producers efficiently. About two-thirds of this dust, however, is screened out before the coal is conveyed to

the overhead bunkers and is not charged into the producers. This discarded coal dust is used for generating steam in the two Duplex plant boilers referred to on page 322. Taking everything into consideration, the coal consumption at the Duplex plant is fairly low and averages 3.25 cwt. per ton of steel ingots produced. This figure includes the coal dust used for firing the boilers.

The following are average analyses of Indian coals:

	Coking coal	Gas coal
Moisture as received.....	5.5	5.7
Total combustible matter.....	79.8	81.4
Volatile matter.....	36.6	36.1
Coke.....	63.4	63.9
Ash.....	14.7	12.9
Sulphur.....	0.603	0.585
Fixed carbon.....	48.7	51.0

The average composition of the gas producer ash after gasifying the gas coal is as follows:

Ash.....	92.42
Volatile matter.....	1.68
Fixed carbon.....	5.90

Coke

The Indian coking coal referred to on page 349 can be converted into a strong, hard coke and that used for fuel in the blast furnaces is manufactured in the Tata Company's own coke ovens already described in Section II. The average coke charged into the blast furnaces passes through a 4-in.-diameter ring. The coke has a very high ash content, usually over 20 per cent, and the percentage of phosphorus is also high, generally over 0.2 per cent, thus furnishing the greater part of the phosphorus content of the pig iron made in the blast furnaces, which ranges from 0.3 per cent to 0.4 per cent. The following is an average analysis of the coke used for blast furnace fuel:

Moisture	5.5
Ash	21.4
Volatile constituents.....	1.5
Sulphur	0.5
Phosphorus	0.22
Fixed carbon	71.0

An average analysis of the coke ash is as follows:

SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Alkalies	SO ₃	P ₂ O ₅
51.75	5.93	29.70	2.28	1.07	0.88	5.84	2.36

The consumption of coke per ton of pig iron manufactured in the blast furnaces is about 2,700 lb. for 'A' and 'B' furnaces, 2,240 lb. for 'E' furnace, and 2,200 lb. for 'C' and 'D' furnaces.

Coke is used at the Duplex plant for ladle fire buckets, smiths' hearths, etc., and is also ground for mixing with the clay and silicious materials composing the mud for packing round the tuyeres for the converter bottoms.

A special Bararee coke is used for recarburizing the steel from the Duplex open-hearth furnaces when required, and is ground into coke dust for this purpose. This coke has the following average composition:

Moisture.....	2.0
Ash.....	17.0
Volatile constituents.....	0.35
Sulphur.....	0.45
Phosphorus.....	0.20
Fixed carbon.....	80.0

The average consumption of coke dust for recarburizing purposes is about $\frac{3}{4}$ lb. per ton of steel ingots produced.

Producer Gas

The gas used as fuel in the Duplex open-hearth furnaces is manufactured in the eight Morgan gas machines previously described in Section III (p. 323), and although the gas coal used for gas making is of inferior quality in comparison with average English and American coals, a fairly good quality of producer gas is obtained of the following average composition:

	Per cent by volume
N ₂	51.2
CO ₂	5.9
O ₂	0.3
CO.....	25.9
H ₂	13.2
CH ₄	3.5
Total combustible gases.....	42.6
B.T.U. per cu. ft. at N.T.P.....	161.5

Coke-Oven Gas and Coal Tar

These by-products are recovered from the Koppers and Wilputte coke ovens, and both coke-oven gas and coal tar are employed for heating the 1,300-ton hot metal mixer, the calcining kilns, and for drying ladles for the mixer, Bessemer converters, and Duplex open-hearth furnaces. Coke-oven gas alone is used for drying the chutes for pouring blown metal into the furnaces, drying the linings of the converters after patching or completely re-lining, and for heating the drying ovens for converter bottoms in the bottom house; and tar alone for heating up the melting chambers and gas and air checkers of the Duplex open-hearth furnaces prior to the admission of producer gas into the furnace when lighting up a cold furnace. Tar is also used for coating the inside of the ingot moulds.

The recovery of coal tar, sulphate of ammonia, and coke-oven gas is effected in the following manner. The gases, in travelling from the gas collecting mains directly over the coke ovens to the primary coolers, become reduced in temperature from 200°C. to 75°C. During this period 70 per cent of the tar is condensed in the oven collecting mains, 20 per cent in the suction mains from the ovens to the coolers, and approximately 8 per cent of the lighter tars and most of the water vapours are condensed in the primary coolers. The liquor and tar from the collecting and suction mains, as well as from the primary coolers, flow to a circulating drain tank, are pumped to the tar separating tank and finally to separator storage tanks, from which the tar is drawn off for commercial use. The gas passes through the tar extractors, where the last trace of tar vapour is extracted, and to lead lined saturators containing a solution of 5 per cent sulphuric acid. The gas coming in contact with the acid gives up all its ammonia, which forms ammonium sulphate. After this acid bath becomes saturated, the crystals of ammonium sulphate fall to the bottom and are ejected upon a draining table. The mother liquor is returned to the saturator and the salt periodically paddled into centrifugal drying machines and finally sent to the sulphate storage rooms where it is bagged or loaded in bulk into wagons for commercial use.

The weak liquor is separated from the tar by gravity in separating tanks and put through ammonia stills where it is brought into contact with a solution of limewater and steam. The lime combines with the ammonium chloride forming calcium chloride. The ammonia is driven off and joins with the gas from the ovens and is sent through ammonia saturators which produce sulphate of ammonia. From the saturators, the gas is passed through final coolers, where it is brought in contact with a water spray and cooled from 60°C. to 25°C., and then piped to a 50,000 cu.-ft.-capacity gas storage tank. An average analysis of the gas is as follows:

<i>Per Cent by Volume</i>						
N ₂	CO ₂	O ₂	CO	H ₂	CH ₄	C _x H _y
12.5	2.5	0.5	8.5	46.5	26.5	3.0
Total Combustible Gases.....						84.5
B.t.u. per cu. ft. at n.t.p.						540

Tar for use at the Duplex plant is either supplied by pipeline from the plate mill storage tank or is delivered in tar tanks on bogies which are shunted from the coke oven by-product plant. In the latter case, the tar is transferred into a tar storage tank in a tar pump house adjacent to the converter bottom house. The tar is then kept hot by steam and is pumped through a circulating system of the return type which prevents the tar from dead-ending and getting cold, and also permits the surplus tar not used in the furnaces, etc., to return to the pumping unit to be used again. Two sets of pumps are provided for forcing the tar to the various burners in the Duplex plant and also to the regenerative reheating furnaces in the blooming mill. Tar is supplied to the burners at a pressure of about 110 lb. per square inch, and steam for atomizing at about 140 to 150 lb. per square inch.

Crude Oil

Occasionally crude oil is used instead of tar, and whenever it is desired to use the former fuel, the circulating system is cleaned out with steam, and the same pumping unit is used for the oil. Crude oil is supplied by the Burmah Oil Company (for which firm the Tinsplate Company of India manufacture tinsplate, chiefly for petrol and oil tins, from tin bar supplied

by the Tata Company). The following is an average composition:

C	H ₂	O ₂	N ₂	S
83.75	12.10	2.65	0.70	0.80

Pig Iron

The composition of the pig iron from the blast furnaces varies according to the purpose for which it is intended to be used. The metal from 'D' blast furnace is at present made solely for the Duplex plant, and is sent to the 1,300-ton hot metal mixer for storage. The average daily output of 'D' furnace is about 700 tons, and the daily requirements of the two Duplex open-hearth furnaces making together on an average 11 heats of 107 tons each per working day — that is, 1,177 tons of steel — is about 1,375 tons of hot metal (allowing for losses), so that about 675 tons has to be supplied by the other blast furnaces. About 1 per cent silicon is aimed at for 'D' furnace metal, and the manganese in the metal is the residual manganese from the charge, no manganese ore being used in this furnace. An average analysis over one month's working is as follows:

Pig iron from 'D' blast furnace

C	Mn	P	S	Si
4.07	0.53	0.334	0.037	1.09

The metal from 'C' blast furnace is at present made purposely for the stationary open-hearth furnaces in the old open-hearth shop. As the average daily output of this blast furnace is about 650 tons, and the daily requirements of the seven stationary open-hearth furnaces working with about 50 per cent hot metal is about 400 tons, this leaves a balance of 250 tons of this metal available for the Duplex plant. The silicon in 'C' furnace metal is kept fairly low for charging into the stationary furnaces, while the manganese is kept up to about 1¼ per cent by the addition of manganese ore to the blast furnace burden. The following is an average analysis over one month's working:

Pig iron from 'C' blast furnace

C	Mn	P	S	Si
4.02	1.23	0.325	0.040	0.75

The pig irons made in 'A', 'B', and 'E' blast furnaces are primarily for commercial use, and only saleable metal is there-

fore manufactured in these furnaces, unless the output of steel from the Duplex open-hearth furnaces is sufficiently high that all the pig iron from one of these blast furnaces can be utilized at the Duplex plant. In this case the composition of the metal from one blast furnace is altered to suit the requirements of the Duplex plant. As the available metal from 'C' and 'D' furnaces is 250 and 700 tons, respectively, that is 950 tons, a further 425 tons is required from one or more of the furnaces 'A', 'B', and 'E', to make up the 1,375 tons of metal required daily by the Duplex open-hearth furnaces. The average daily output of each of 'A' and 'B' furnaces is from 350 to 400 tons of basic pig iron, say 750 tons for the two, and from 'E' furnace about 400 to 450 tons, say 425 tons, which makes a total of 1,175 tons for these three furnaces when all are working; therefore about 750 tons daily is available for sale after supplying the Duplex plant with 425 tons. The saleable metal is therefore cast into pigs in sand, or in the pig casting machine described in Section III (page 312). The following are average analyses taken over one month's working of 'A', 'B', and 'E' blast furnaces:

	C	Mn	P	S	Si
Pig iron from 'A' blast furnace..	3.88	1.31	0.359	0.034	1.41
" " " 'B' " " " ..	3.97	1.22	0.348	0.035	1.34
" " " 'E' " " " ..	3.98	0.82	0.341	0.037	1.08

Silicon is the most important element in the pig iron used in the Duplex process since it furnishes the larger part of the heat during the blow in the Bessemer converter, and it must therefore be present in sufficient amount to give enough heat to the charge and to prevent any skulling of the blown metal in the ladle. Beyond this amount its presence lengthens the time of the blow and therefore increases the power cost, and also decreases the number of blows on the converter bottoms and tuyeres. Moreover, too high a silicon content is objectionable on the ground that it may subsequently retard the dephosphorization of the metal in the open-hearth furnace, as explained in Section V (page 410). On the other hand, a blast furnace cannot desulphurize its iron product if the iron is too low in silicon, while increased silicon content of the iron means greater coke consumption in the blast furnace.

The manganese content of the pig iron is also important, for, if it is very low, 'kidneys' are liable to form in the converter

(especially if the silicon be high), while if the percentage of manganese is too high the acid lining of the converter will be attacked by the excess of basic MnO formed during the blow, and, in addition, 'slopping' of the metal is likely to take place on account of the mobile character of the slag formed. These results of variations in the composition of the pig iron are more fully discussed in dealing with the Bessemer practice in Section V (page 376).

The most satisfactory composition of the pig iron to be employed for the Duplex process is from 0.90 to 1.20 per cent silicon, with about 0.70 to 0.80 per cent manganese, and the sulphur should not exceed 0.045 per cent. This composition, therefore, is aimed at in the hot metal mixer, and after taking all 'D' blast furnace metal and the available 'C' furnace metal, both of which are usually unsaleable, the metal still required for the Duplex open-hearth furnaces is taken from 'A', 'B', or 'E' blast furnaces, whichever metal is most suitable at the time for maintaining the metal in the 1,300-ton mixer as nearly as possible to the above composition. The following is an average analysis of metal from the 1,300-ton hot metal mixer during one month's working:

Pig iron from 1300-ton hot metal mixer

C	Mn	P	S	Si
3.95	0.77	0.344	0.034	1.07

Ferro-manganese and Spiegel

These steel-making alloys are manufactured from Indian manganese ore by the Tata Company in one of the blast furnaces. The furnace employed for this purpose is usually that which has the oldest lining, so that the excessive corrosion of the lining which occurs when this alloy is being produced does not take place in a furnace which has been comparatively newly-lined. Although rich manganese ore is available in large quantities, it is impossible to produce an 80 per cent ferro-manganese owing to the high iron and phosphorus content of the ash from the coke charged in the blast furnace, but with care a 75 per cent alloy, with phosphorus under 0.6 per cent, can be obtained. Another grade of ferro-manganese with a higher phosphorus content, averaging about 1.75 per cent, is also manufactured for use at the Duplex plant. This high phosphorus alloy is employed instead of ferro-phosphorus

in making sheet-bar and tin-bar steels whenever the percentage of phosphorus in the open-hearth furnace bath is very low, in order to lift the phosphorus content of the finished steel above the minimum required (0.030 per cent). Average analyses of the ferro-manganese produced are as follows:

	C	Mn	P	S	Si
High-phosphorus ferro-manganese.....	5.95	66.0	1.75	0.022	1.51
Low-phosphorus " ".....	5.90	73.5	0.55	0.025	2.35

Any low-grade ferro-manganese falling below 40 per cent Mn which is made in the blast furnace when changing from pig iron to ferro-manganese manufacture, and vice versa, is classed as a spiegel and is graded into classes according to its manganese content. An average composition of spiegel produced during one year is as follows:

C	Mn	P	S	Si
5.05	26.75	0.60	0.020	1.75

Spiegel is, therefore, not purposely manufactured, and is only produced in small amounts and occasionally added to the open-hearth furnace bath in place of its equivalent of ferro-manganese in order to use up the stock. The amount of ferro-manganese consumed varies, of course, for different grades of steel, the average consumption per ton of steel ingots produced being as follows:

For rail steel (C, 0.55-0.65%; Mn, 0.65-0.85%).....	32.5 lb.
For structural steel, T. F. grade (C, 0.22-0.26%; Mn, 0.50-0.70%)..	30.0 lb.
For tin-bar steel (C, 0.10-0.14%; Mn, 0.40-0.60%).....	21.0 lb.
Average residual bath, manganese 0.10 %	

Ferro-silicon

This alloy is imported and is of a very high grade, averaging 78.35 per cent Si and 19.2 per cent Fe. It is added to the ladle for various steels, the average consumption per ton of steel ingots produced being 0.75 lb. for rail steel, 1.68 lb. for structural steel, and 3.36 lb. for tin-bar steel.

Ferro-phosphorus

This alloy is also imported and has been occasionally added in the ladle for increasing the percentage of phosphorus in the steel for sheet-bar and tin-bar when required, but now

the high-phosphorus ferro-manganese already referred to is used instead. An average analysis of ferro-phosphorus is given below:

C	Mn	P	S	Si	Fe
0.70	3.97	25.08	0.20	7.54	62.40

Aluminium

This is imported in both notched bar and shot form, and is 99 per cent pure. The average amount consumed per ton of steel ingots is 2 ounces for rail steel, 3½ ounces for structural steel, and 4 ounces for tin-bar steel.

SECTION V. THE WORKING OF THE DUPLEX PROCESS

(a) Blast Furnaces to Hot Metal Mixer

As previously stated, iron from the blast furnaces is cast into 60-ton ladles mounted on special trucks which are shunted by steam locomotive to the Duplex plant mixer house ⁽¹⁾, where the ladles are lifted from their trucks by a 100-ton overhead ladle crane and the contents tilted by means of a 25-ton auxiliary hoist into the 1,300-ton hot metal mixer through the pouring-in spout.

The major portion of the slag from the blast furnaces during tapping is run into special steam dump slag ladles, but a small amount necessarily enters the ladle with the metal. This slag is held back with a rake (consisting of a block of wood 4-in. thick fixed to an iron handle) during the pouring of the metal into the hot metal mixer to prevent as much as possible from entering, for an excessive amount of slag in the mixer is objectionable in that it considerably reduces the storage capacity of the vessel for metal. Furthermore, if much slag from the mixer enters the transfer ladle and becomes charged into the Bessemer converter, it attacks the converter lining and also causes 'slopping' of the metal and slag over the mouth of the latter vessel during blowing, as explained on page 379. When the metal contents have been poured into the hot metal mixer, the blast furnace ladles are cleared of slag or 'kish' as much as possible by dumping it into slag pans,

⁽¹⁾ The intervening distance is about ¾ mile.

after which the ladles are replaced on their trucks and re-shunted to the blast furnaces. Average analyses of blast furnace slags are as follows:

	Dolomite used as flux	Limestone used as flux
SiO ₂	29.25	29.32
Al ₂ O ₃	20.88	23.33
CaO.....	28.76	41.10
MgO.....	17.56	2.05
FeO.....	1.71	2.43
MnO.....	1.34	1.09

The metal is weighed on the blast furnace plant weigh-bridge before being shunted to the Duplex plant mixer house, and again when being poured from the mixer into the transfer ladle for the Bessemer converters, and the average loss due to oxidation and skulling is found to be approximately 1½ per cent. Of this loss, about 1 per cent takes place in transferring the metal from the blast furnaces to the hot metal mixer.

A sample for analysis is, of course, taken from every cast of pig iron from each blast furnace. Average analyses have been given on earlier pages.

(b) *Hot Metal Mixer to Bessemer Converters*

Although the original capacity of the hot metal mixer was 1,300 tons, its maximum capacity is now only about 800 tons owing to the thickness of the magnesite lining of the mixer bottom having been considerably increased since the mixer was first built. It is now usually worked with a maximum charge of about 700 tons, which is quite sufficient for the requirements of the Duplex plant.

As the Duplex open-hearth furnaces are usually not requiring metal each week-end from about 5 p.m. on Saturday to about 6 a.m. on Sunday, all the metal from 'D' blast furnace (or the furnace making pig iron solely for the Duplex plant when 'D' furnace is blown-out for repairs) cast between

these hours, amounting to about 375 tons, has to be taken care of by the Duplex mixer, and to allow for this metal the contents of the mixer are reduced to about 250 to 300 tons on Saturday mornings by not taking metal from 'A', 'B', and 'E' blast furnaces, which metal is cast into pigs in the sand beds or in the pig casting machine. In the same way, the 300-ton hot metal mixer for the stationary open-hearth furnaces takes care of metal from 'C' blast furnace, so that only saleable pig iron is cast.

As stated in Section IV (page 356), the most suitable composition of pig iron for blowing-in the Bessemer converter is 0.90 to 1.20 per cent silicon with about 0.70 to 0.80 per cent manganese, which is regulated by the different compositions of blast-furnace metal, and during the week-ends, when only metal from 'D' blast furnace can be taken, the composition of this metal is temporarily altered by variations in the blast furnace burden to approach as nearly as possible the required mixer metal analysis given above.

If the mixer is full at 6 a.m. on Sundays and the Duplex open-hearth furnaces are not ready for charging, owing to some delay due to fettling, repairs, breakdown, etc., any further metal from 'D' blast furnace which arrives at the Duplex plant is held in the ladle until a furnace is ready for charging (that is, if the delay is not likely to be of long duration). As soon as the metal is required, it is poured direct into the converter transfer ladle (without the metal passing through the mixer), either by means of the 100-ton ladle crane and 25-ton auxiliary hoist serving the mixer house, or by the similar crane at the furnace charging side, the gantry for the latter crane being extended over the Bessemer converters; and only in cases of emergency is this unsaleable metal from 'D' blast furnace sent to the pig casting machine.

The metal is dealt with in this manner whenever it is being received from the blast furnaces while the hot metal mixer is full, the excess metal being poured from the blast furnace ladle direct into the converter transfer ladle. The same practice is also followed when the mixer is down for relining or mechanical repairs, or whenever the mixer house

ladle crane is out of order, in which latter case the metal is poured into the converter transfer ladle by means of the ladle cranes serving the furnace at the charging side.

It is the usual custom on Sunday mornings to take a cast or two of metal from 'A' or 'B' blast furnace. This metal is generally higher in silicon than normally required, and is poured direct into the transfer ladle and thence into the Bessemer converters, in order to secure sufficient heat from the first few blows to heat up the converters after the week-end shut-down.

Whilst the metal is in the mixer, it undergoes purification to a small extent, owing to some of the sulphur forming manganese sulphide, which rises to the top of the metal and passes into the slag. The percentage of carbon, manganese, and silicon is also slightly reduced owing to their oxidation during the heating of the metal by means of tar and coke-oven gas. A little free carbon or graphite also separates out from the metal in the mixer, so that some of the slag becomes a mechanical mixture of slag and graphite, which is infusible at the mixer temperature and can be raked out of the mixer pouring-out spout as if the mixture were hot sand. Flakes of graphite can be observed being deposited around the mixer house during the pouring of the metal either into or out of the mixer. The following is a typical analysis of mixer slag (freed from graphite) for comparison with the blast furnace slag:

SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	FeO	MnO	CaO	MgO	TiO ₂	Sul.	P ₂ O ₅
32.40	11.71	9.76	22.44	1.03	15.80	1.08	5.52	0.10	trace

The average temperature at which the molten blast furnace metal enters the mixer is about 1,350°C. and the metal is kept hot by the employment of coal tar and coke-oven gas burners. These are directed on to the metal through the pouring-out spout, and through a port at each end of the mixer.

As soon as hot metal is required for the Bessemer converters, the mixer is tilted and approximately 22 tons of metal poured into a 30-ton ladle supported on a special transfer carriage. It is important that the metal poured out of the mixer is not too hot, especially when the silicon content is high, otherwise, too high a temperature of the Bessemer

blown metal will be attained, with the result that difficulty in the elimination of phosphorus in the basic open hearth may be experienced, as explained later in the paper. The temperature of the mixer metal transferred to the converters should, therefore, be from $1,275^{\circ}\text{C.}$, to $1,300^{\circ}\text{C.}$, and should not exceed the latter temperature.

The ladle and carriage while in position under the mixer pouring-out spout stand on a 100-ton weighbridge, and the metal is thereby weighed. Directly the required amount has been poured, the mixer is tilted back into its normal position. The transfer ladle on its carriage is then hauled by the electrically operated wire rope to a position in front of one of the Bessemer converters, and the contents are charged into the vessel by means of the 17-ton jib crane, also electrically operated, the ladle being tilted while supported on the carriage.

The loss of iron during mixing averages about 0.5 per cent, so that the average yield from blast furnaces to converters is about $98\frac{1}{2}$ per cent.

Repairs to the mixer lining are required about every twelve months, and, while these repairs are being executed, metal from the blast furnaces is poured direct into the converter transfer ladle and thence into the converters in the manner described on page 360.

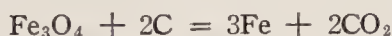
Samples of mixer metal for analysis are taken every three or four hours during the pouring of the metal into the converter transfer ladle. An iron spoon is used for sampling, and the contents of the spoon are then poured into a clay mould and allowed to cool down to a black heat before the sample is chilled off for drilling. If a cast iron mould is used, the skin of the sample becomes hardened by being chilled, thus making the sample very difficult to drill.

(c) *Bessemer Converters to Open-Hearth Tilting Furnaces*

For receiving the mixer metal, the converter is rotated into a horizontal position, and as soon as the ladle and transfer car are removed, air blast is turned on, after which the converter is slowly turned up into an almost vertical position in which it is maintained during the blowing of the metal, except that the position of the vessel is slightly altered at intervals in order

to facilitate the oxidation of the elements. When the vessel is being turned up at the commencement of the blow, metal flows over the tuyeres in the converter bottom, and the air, in forcing its way through the metal, causes a vigorous ejection of sparks which are minute particles of molten iron. As the metal becomes deeper over the tuyeres, the ejection of the sparks diminishes but does not entirely cease and as soon as the converter is turned into a vertical position a vigorous reaction commences.

If the initial temperature of the mixer metal is not too high, the greater portion of the silicon and manganese of the metal is oxidized during the early period of the blow and the oxides of these elements unite with some oxide of iron, simultaneously produced, to form a double silicate of iron and manganese slag. It is generally admitted that the oxidation of the elements is an indirect reaction, and that the air in contact with the iron forms magnetic oxide of iron (Fe_3O_4) which is then decomposed by the silicon, manganese, and carbon. Under normal conditions of working, the carbon is not appreciably attacked until a considerable portion of the silicon has been removed, such proportions as are oxidized passing away mostly as carbon dioxide, thus:



Silicon is the most readily oxidizable element in the metal, and so great is its reducing action that it is capable of decomposing to a large extent any CO produced, giving rise to the formation of carbide of iron (Fe_3C) and so preventing the oxidation of the carbon during the early stages of the blow.

At first there is very little flame and only a stream of hot gas and a shower of sparks are observed, for the gas which leaves the converter is mainly the nitrogen of the air forced through the metal, as the oxygen is absorbed in the early stages by the following reaction:



The manganese is also oxidized very early in the blow and passes into the slag as silicate of manganese, for, if no free acids are present, manganese is able to displace iron from iron silicate, thus:



In about two minutes a decided flame makes its appearance at the converter mouth. This flame is at first irregular and violet coloured, but soon becomes more steady in character and changes to a yellowish-red colour as the temperature of the bath increases; but up to this stage the flame is small and but slightly luminous.

After about five minutes from the commencement of the blow, during which time the temperature has been rapidly rising and thus causing an increase in the fluidity of the metal owing to the heat produced by the combustion of the silicon, the carbon begins to oxidize rapidly and the flame becomes larger and more luminous, and the boil, as it is known, commences. During the boiling period, the flame at first is very unsteady but it gradually increases in steadiness, density, and luminescence; for as soon as the oxidation of the silicon and manganese is almost complete, the carbon is rapidly removed from the metal, mostly in the form of carbon monoxide, thus:



for the percentage of CO_2 formed in the early part of the blow very quickly decreases, while the CO , which is combustible and burns at the mouth of the converter, increases. It is the formation and escape of this gas that causes the violent agitation of the bath, and is attended with a very large flame issuing from the converter mouth or nose, and with the ejection of showers of sparks and minute particles of iron which burn as they come into the air. These oxidized iron particles may be observed deposited as very small globules or shot around the converters, and they also gradually accumulate in heaps in the direction in which the vessels are turned down at the end of the blow. This shot is periodically collected and used for the purposes stated in the paragraph on mill scale in Section IV, page 334, where an average analysis is also given.

Some hydrogen derived from the dissociation of any water vapour in the blast is also found in the gases issuing from the converter mouth.

Instead of blowing all heats down until the carbon, silicon, and manganese are almost completely removed from the metal, as in the ordinary acid Bessemer process of steel making,

the carbon is caught by stopping the blow at an early stage of the boil whenever a high-carbon blow or 'kicker' is required for the Duplex open-hearth furnaces. These 'kickers', the object of which is explained later in the paper, vary in carbon according to the grade of steel to be produced in the basic open-hearth, and in Table X the percentage of carbon for various blows, together with the residual silicon and manganese, and the average duration of the blows, are shown:

Table X.—Composition of Bessemer blown metal required for various grades of basic open-hearth steel

Carbon required at end of blow	Average residual silicon	Average residual manganese	Average duration of blow, in minutes	Designation of blow and grade of basic open-hearth steel for which blow is required
%	%	%		
2.50 to 2.75	0.15	0.22	6	Final 'double-kicker' for rail steel (0.55 to 0.65% C.)
1.50 to 1.75	0.07	0.13	9½	Final 'single-kicker' for structural steel (0.22 to 0.26% C.)
1.00	0.04	0.10	11½	Preliminary 'single-kicker' for rail steel (0.55 to 0.65% C.)
0.10	0.01	0.06	14½	Final 'single-kicker' for sheet-bar and tin-bar steel (0.10 to 0.14% C.)
				Soft blows for all steels.

The following curves (Figure 2), which are plotted from analyses taken over a period of six months, illustrate the rate of oxidation of the carbon, silicon, and manganese during the blow under normal conditions; that is, with an average air blast of 21 lb. per square inch in the converter wind box and an average weight of 22 tons of mixer metal of the composition previously specified in the paragraph on pig iron in Section IV (page 356) of the paper, *viz.*,

C	Mn	P	S	Si
3.95	0.77	0.344	0.034	1.07

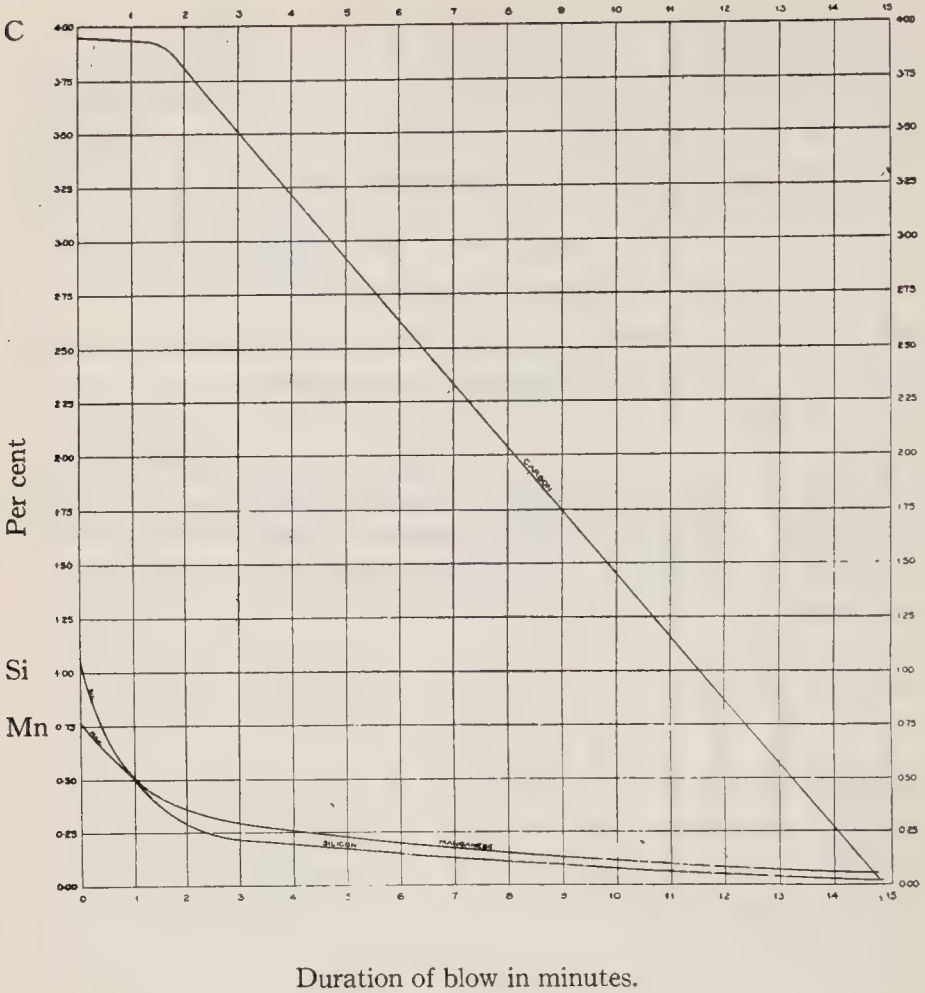


Figure 2.—Curves showing average rate of oxidation of carbon, silicon, and manganese in the Bessemer converter during blowing.

The duration of the blow necessarily depends on the pressure of the blast, the number of tuyeres blanked off, and the weight and composition of the metal from the mixer. The blast pressure is, of course, primarily dependent on the speed and capacity of the air compressors in the blowing house. Table XI shows the rated air pressure, speed, and load of the two 28,000 cubic-foot-capacity air compressors, in comparison with actual averages obtained during one month's run:

Table XI.—Particulars of air compressors for blowing Bessemer converters

	Compressor					3,600 h.p. motor
	Duration of blow, in minutes	Air pressure, in lb. per sq. in.	Revolu- tions per minute	Inlet air temp., in deg. F.	Dis- charge air temp., in deg. F.	Load in kilo- watts
Rated.....	.....	31.5	3,520			2,700
Actual average....	12.75	26.0	3,480	84	330	3,000

Although the average air pressure supplied by the compressor is 26 lb. per square inch, as recorded by the pressure gauges and recording chart in the blower house, there are pipe line losses amounting to 5 lb. per square inch between the compressor and the converter wind box, so that the actual average blast pressure at the tuyeres is 21 lb. per square inch.

As previously stated, there is a Bristol pressure recording chart located near the converters, and Figure 3 is a duplicate of a chart illustrating the variations in pressure during a period of 24 hours.

When soft blows are required, the blow is continued until the carbon, silicon, and manganese are almost completely removed from the metal. After about 14 minutes the flame begins to flutter, becomes less luminous and not so dense, and also diminishes in volume. All at once the flame suddenly drops and the blow is completed.

Immediately the steel blower in the blowing pulpit opposite the converters judges that the desired carbon of any blow has been reached, he turns down the vessel, and at the same time steadily reduces the blast by gradually switching off the compressor motor.

The metal is then poured from the converter into a 40- or 60-ton ladle supported on a special truck which runs on rails on ground level beneath the converters, the larger ladles being used for double blows. The truck and ladle of metal

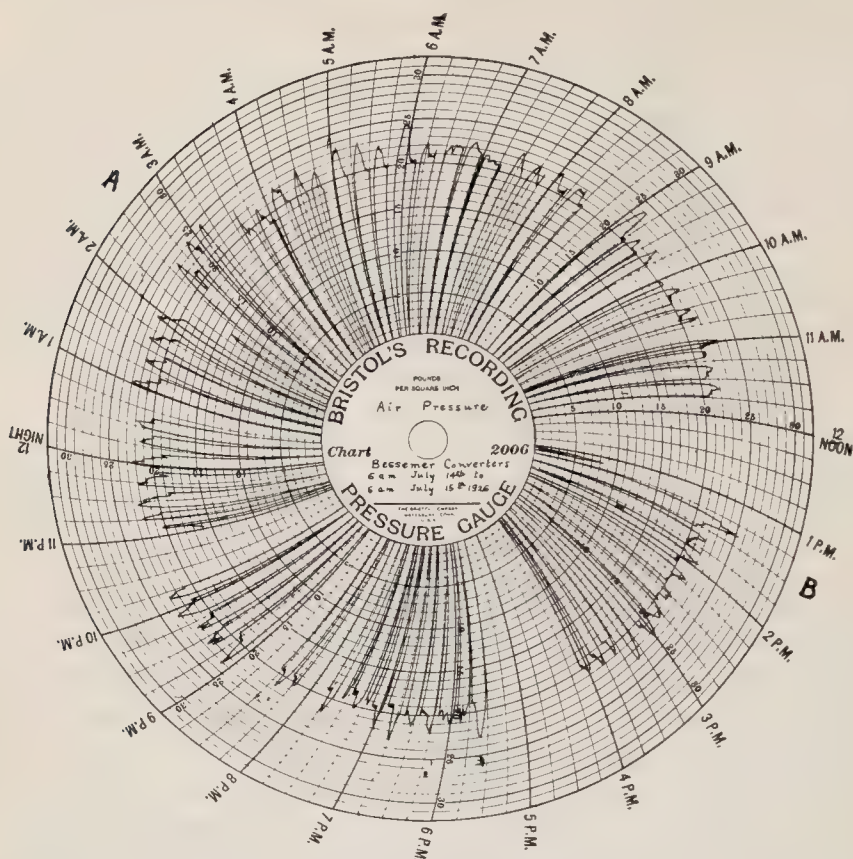


Figure 3.—Air pressure recording Chart for Bessemer converters.

- A—(between 2 a.m. and 3 a.m.): 5-ton trial blow on new bottom.
 B—(between 1 p.m. and 2 p.m.): 5-ton trial blow on new bottom.

are then shunted by steam locomotive clear of the converters and on to a 150-ton weighbridge, by which the weight of blown metal is obtained and recorded. This is done by taking the gross weight of the truck, ladle and contents before the metal is taken to the open-hearth furnaces, and re-weighing the ladle and truck on its return journey to the converters, after the metal has been poured into the furnace, the difference being, of course, the net weight of metal. If the tare weight of the ladle and truck is at any time greater than when previously weighed, it is due to skull having formed in the ladle. It often happens that a skull formed by one heat of cold-blown metal is more or less removed by a succeeding heat which has attained a much higher temperature. In this case the tare weight of the ladle and truck is less than the preceding weight.

After the gross weight has been taken, the ladle is lifted from the truck by one of the 100-ton ladle cranes serving the open-hearth furnaces. As much acid slag as possible is poured off into a slag pan by tilting the ladle with the 25-ton auxiliary hoist, after which the ladle pouring lip is cleared and shaped with clay and the ladle then carried to the open-hearth furnace requiring the metal.

Specially designed chutes, which are manipulated in a similar manner to the charging boxes by the $3\frac{1}{2}$ -ton furnace platform charging machine, are provided for transferring the metal from the ladle into the furnace. While the ladle is being conveyed from the converter to the furnace, one of these chutes, which has been lined with firebricks and thoroughly dried, is placed in front of one of the furnace doors in readiness for receiving the metal. The base of the chute stands on the furnace platform, while the spout passes through the furnace doorway under the door which has been lifted. After the chute has been placed into position, the ladle is tilted by the auxiliary hoist and the metal contents poured down the chute into the furnace bath.

While the metal is being poured from the converter into the ladle, a sample for analysis is caught in an iron spoon. For the 1 per cent and lower carbon blows, the metal from the sampling spoon is poured into a cast iron mould, and the sample, after cooling, is drilled for analysis, usually the carbon only being determined. For the $2\frac{1}{2}$ to $2\frac{3}{4}$ per cent, and $1\frac{1}{2}$ to $1\frac{3}{4}$ per cent carbon blows the metal is poured from the sampling spoon into either a clay mould, or an iron mould lined with clay, or else into a pan of water. In the latter case, the sample takes the form of shot, some of which is collected and placed in a steel mortar and pulverized with a steel pestle by striking it with a heavy hammer. The latter method of sampling is usually adopted, owing to the difficulty experienced in drilling block samples unless great care is taken to prevent the hardening of the skin of the sample by too sudden chilling.

With regard to the sulphur and phosphorus content of the metal, the former element is not removed at all during the blow, but is rather inclined to increase owing to the original weight of sulphur being present in a reduced weight of metal after the blow, and whereas the average percentage of sulphur

in the mixer metal is 0.034 per cent, this is increased to 0.037 per cent in the blown metal. On the other hand, phosphorus is removed to a small extent, possibly by volatilization, as its removal by oxidation is prevented by the large amount of SiO_2 present in the converter lining in contact with the metal. The only form in which phosphorus could be oxidized would be as phosphate of iron, but this is decomposed by SiO_2 , P_2O_5 being liberated and decomposed by the iron with the formation of iron phosphide and oxide. The average phosphorus content of a large number of heats of blown metal was 0.283 per cent, while the average phosphorus content of the mixer metal before blowing during the same period was 0.344 per cent, so that there was approximately 18 per cent less phosphorus in the metal after the blow. It will be observed from the average composition of converter ladle slag given on page 94 that 0.048 per cent P_2O_5 is contained in the slag, but this amount is insufficient to account for all the phosphorus removed from the metal.

A certain amount of manganese, silicon, and iron, especially the last, which is, of course, present in great excess, is also volatilized and accounts for some of the metal lost during the blow.

The yield of blown metal from mixer metal from actual weighings is $91\frac{1}{2}$ per cent, the $8\frac{1}{2}$ per cent loss being due to oxidation, volatilization, and ejection of metal during the blow ⁽¹⁾, and to occasional skulls formed in the converters and ladles. The total yield, therefore, from the blast furnaces to the Duplex open-hearth furnaces, that is, from blast furnace metal to converter blown metal, is approximately 90 per cent. The $8\frac{1}{2}$ per cent loss of metal owing to oxidation, etc., can be accounted for as follows:

C.....	3.95%
Mn.....	0.77%
Si.....	1.07%

⁽¹⁾ Some metal enters the slag in the form of shot, the amount having been found by magnetic separation to average about 6 per cent of the weight of the slag sample, which means that about $\frac{1}{4}$ per cent of the iron from the converter is lost in this manner.

(a) Carbon:

The loss of this element by oxidation to CO_2 early in the blow, and later to CO , depends on the percentage of carbon left in the finished blow. The average carbon content of all heats of blown metal during a period of one month was 0.55 per cent, so that, allowing for the smaller weight of metal after the blow, this equals $(0.55 \times 91.5) \div 100 = 0.50$ per cent on the weight of mixer metal. Therefore the average percentage of carbon oxidized was $3.95 - 0.50 = 3.45$ per cent.

(b) Manganese:

The average percentage of residual manganese during one month was found to be 0.10 per cent; $(0.10 \times 91.5) \div 100 = 0.09$ per cent; therefore the average percentage of manganese oxidized was $0.77 - 0.09 = 0.68$ per cent.

(c) Silicon:

An average, taken during one month, of the residual percentage of silicon was found to be 0.04 per cent. This amount is only slightly affected by the smaller weight of metal after the blow, so that the average percentage of silicon oxidized was $1.07 - 0.04 = 1.03$ per cent.

(d) Iron:

The percentage of iron oxidized is only obtainable from the analysis of the slag, for although a considerable amount of iron becomes oxidized to Fe_3O_4 in the early stages of the blow, some of it is subsequently reduced by the carbon to Fe_2O_3 and FeO , and the remainder still further to Fe , which passes back into the metal.

From the analysis of the converter slag given on page 373 we have,

SiO_2	55.15%
FeO	12.41%
Fe_2O_3	4.40%

As the amount of silicon oxidized from the mixer metal is 1.03 per cent and the average weight of metal blown in the converter is 22 tons (49,280 lb.), therefore the weight of silicon oxidized is $(49,280 \times 1.03) \div 100 = 507.6$ lb.

Assuming that all the silicon is oxidized to SiO_2 , which forms a ferrous silicate slag with oxide of iron, and that the amount of silicon lost by volatilization is counterbalanced by the gain of silica from the wearing of the converter lining and erosion of the bottom, the weight of SiO_2 produced is

$$(507.6 \times 60) \div 28 = 1,087 \text{ lb.}$$

$$(\text{Atomic weight of Si} = 28; \text{O} = 16).$$

As the average content of SiO_2 in the slag is 55.15 per cent, therefore the maximum weight of slag which can be produced is $(1,087 \times 100) \div 55.15 = 1,971 \text{ lb.} = 4 \text{ per cent of the original weight of metal.}$ The percentage of iron contained in the slag is therefore

12.41 × 56	}	12.73 per cent total Fe
72		
4.40 × 112	}	
160		

From $\text{FeO} \dots\dots\dots = 9.65$

From $\text{Fe}_2\text{O}_3 \dots\dots\dots = 3.08$

Therefore the percentage of iron lost from the metal amounts to $(12.73 \times 4) \div 100 = 0.51 \text{ per cent.}$

The $8\frac{1}{2}$ per cent loss of metal is therefore made up as follows:

	%		%		%
Oxidation of carbon.....	3.45	}	= 5.67	}	8.50
“ “ manganese.....	0.68				
“ “ silicon.....	1.03				
“ “ iron.....	0.51				
Shot in slag.....	0.25	}	= 2.83	}	
Skulls from actual weighings.....	0.88				
Volatilization and ejection of metal.....	1.70				

With reference to the slag formed by oxidation of the elements during the blow, any slag left in the converters after pouring all the metal after the blow into the ladle for the open-hearth is dumped into a slag pan on a bogie running on rails at right angles to the track for shunting the open-hearth ladle trucks towards the furnaces.

An average of a considerable number of ladle samples of normal converter slag, which has a dark grey fracture, is as follows:

SiO ₂	55.15
Al ₂ O ₃	5.25
Fe ₂ O ₃	4.40
FeO.....	12.41
MnO.....	19.50
CaO.....	1.35
MgO.....	0.39
TiO ₂	1.18
P ₂ O ₅	0.048
S.....	0.053

From calculations based on the above slag analysis, it is found that a certain percentage of manganese is lost by volatilization and ejection of metal during the blow, *e.g.*:

The approximate weight of slag determined from the silicon content of the metal and the silica content of the slag was found to be 1,971 lb. As 0.68 per cent Mn has been oxidized from 49,280 lb. metal, this equals $(0.68 \times 49,280) \div 100 = 335.1$ lb. Mn, whereas the slag contains 19.5 per cent MnO on a weight of 1,971 lb., which equals

$$\frac{19.5 \times 1971 \times 55}{100 \times 71} = 297.7 \text{ lb. Mn}$$

Therefore $335.1 - 297.7 = 37.4$ lb. Mn are lost by volatilization, etc., which equals 0.075 per cent on the original weight of mixer metal.

If the weight of slag is calculated from the MnO content, and the loss of any manganese by volatilization is ignored, then the result obtained is somewhat higher than if SiO₂ is taken as the basis of the calculations. In the latter case, the weight of slag has been found to be 1,971 lb., whereas in the former case the weight is 2,218 lb., *e.g.*:

It has already been calculated that 335.1 lb. of Mn are removed from the metal. This equals $(335.1 \times 71) \div 55 = 432.5$ lb. MnO. $432.5 \text{ lb. MnO} = 19.50$ per cent MnO in the slag. Therefore the weight of slag = $(432.5 \times 100) \div 19.5 = 2,218$ lb.

However, as it is known that some manganese is volatilized during the blow, the weight of slag calculated by the above method is certain to be more than is actually obtained in practice.

From the slag analysis can also be calculated the amount of iron which is either volatilized or returned to the metal after first being oxidized early in the blow and subsequently reduced by the carbon during the boil, *e.g.*:

(a) It has been shown that the percentage of Mn oxidized from the mixer metal during the blow is 0.68, which forms manganese silicate (Mn_2SiO_4) with the silica produced.

As $2 \times 55 = 110$ units Mn require 28 units Si, therefore 0.68 per cent Mn requires $(0.68 \times 28) \div 110 = 0.173$ per cent Si.

(b) The percentage of Si oxidized from the mixer metal is 1.03, which forms ferrous silicate (Fe_2SiO_4) with Fe_3O_4 .

As 0.173 per cent Si is required by the Mn, this leaves $1.03 - 0.173 = 0.857$ per cent Si for combination with the iron.

(c) The iron required by 0.857 per cent Si for the production of Fe_2SiO_4 by oxidation is calculated as follows:

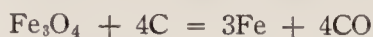
28 units Si require $2 \times 56 = 112$ units Fe. Therefore 0.857 per cent Si requires $(0.857 \times 56) \div 28 = 1.714$ per cent Fe, which, on 49,280 lb. mixer metal = 844.6 lb. Fe.

The percentage of Fe_2O_3 in the slag is 4.40 per cent, and of FeO 12.41 per cent. Therefore the weight of Fe in the slag is as follows:

$$\begin{array}{rcl}
 \text{Fe}_2\text{O}_3 \dots\dots\dots & \frac{4.40 \times 1971 \times 112}{100 \times 160} = 60.7 \text{ lb.} & \\
 \text{FeO} \dots\dots\dots & \frac{12.41 \times 1971 \times 56}{100 \times 72} = 190.2 \text{ lb.} & \\
 & & \left. \begin{array}{l} \\ \\ \end{array} \right\} \begin{array}{l} \\ \\ \text{total Fe in the slag.} \end{array}
 \end{array}$$

Therefore the difference in weight between the Fe found in the slag and the Fe theoretically required by the silicon is $844.6 - 250.9 = 593.7$ lb. Fe = 1.2 per cent on the original

weight of mixer metal. This disparity to a certain extent may be due to volatilization of iron, but most of it is probably accounted for by the reduction of some of the magnetic oxide of iron formed in the early part of the blow by the carbon removed during the boil according to the equation:



This seems to be proved by the representative analyses given below in Table XII of converter slag samples taken at the end of the blow for the different carbons previously specified in Table X, page 365.

Table XII.—Analyses of converter slag samples at different stages of the blow

Composition of metal at end of blow, per cent			Composition of slag at end of blow, per cent				
C	Si	Mn	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO
2.50 to 2.75	0.15	0.22	50.94	4.78	5.18	20.16	17.47
1.50 to 1.75	0.07	0.13	55.88	5.41	4.23	14.37	18.40
1.00	0.04	0.10	58.23	5.92	3.95	8.81	19.95
0.10	0.01	0.06	54.86	5.18	4.38	12.02	19.83

It is generally agreed that the volatilization of Si, Mn and Fe takes place during the blow, for the oxides of these elements have been found to be present in the fume produced. The analysis of fume given by Schöffel ⁽¹⁾ is as follows:

FeO.....	16.29
MnO.....	48.23
SiO ₂	34.86

Therefore, if silicon is volatilized, the weight of slag produced would be somewhat less than the 1,971 lb. obtained by the preceding calculations, in which any loss of silicon from the metal which might have occurred owing to volatiliza-

⁽¹⁾ *Vide* "The Metallurgy of Steel" by F. W. Harbord, page 79.

tion has been ignored; but on the other hand, the weight of slag may be higher than calculated owing to the wear of the converter lining and erosion of the bottom.

It has already been stated that the most suitable composition of the mixer metal for the Duplex process is 0.90 to 1.20 per cent Si and 0.70 to 0.80 per cent Mn, and that the average content of these elements during one month was 1.07 per cent Si and 0.77 per cent Mn. The reason for the selection of metal of this composition is that it has been found in practice to give the most satisfactory results, in that the silicon is just sufficient to generate the necessary heat to prevent sculling of the ladles and furnace pouring chutes, and the manganese is just sufficient to obtain the maximum yield of blown metal without the MnO formed attacking the silica lining of the converter.

A high silicon content of the mixer metal is objectionable because it lengthens the duration of the blow and consequently causes an increase in the electric power consumption of the turbo-blowers, and it also causes the metal to attain too high a temperature, so that it has to be cooled down during the blow by blowing steam through the tuyeres with the air, and also by adding cold scrap to the metal in the ladle after the blow. The cooling of excessively hot blown metal is necessary because, if it is poured into the open-hearth at a much higher temperature than that of the furnace bath, the equilibrium between the slag and metal in the bath becomes so disturbed that considerable difficulty is experienced in keeping down the phosphorus content of the metal, as explained later in the section on the open-hearth process (page 410).

If a very high temperature is attained during the blowing of metal with a high silicon content, it is highly probable that a considerable portion of the original silicon will be found in the blown metal after the carbon has been removed to the desired extent. This residual silicon is very undesirable as it becomes subsequently oxidized to silica after the metal has been charged into the basic open-hearth furnace, with the result that it interferes with the elimination of phosphorus from the metal in the open-hearth bath, in the manner described

later. The residual silicon in the blown metal may either be due to the fact that it has never been eliminated, or it may have been first removed by oxidation and subsequently reduced from the slag at an excessively high temperature, and thus have entered the metal again, as frequently occurs in the acid open-hearth furnace. Under normal temperature conditions, silicon is almost completely eliminated before the carbon is oxidized to any great extent, but at very high temperatures carbon has a greater affinity than silicon for oxygen, with the result that the former element is rapidly removed while the silicon remains practically unaffected. This silicon can be removed, however, by continuing the blowing, after the carbon has been eliminated, until heavy brown fumes are evolved which indicate that all the silicon has been slagged; but this can only be done for soft blows and is not applicable to high-carbon blows or 'kickers'.

Occasionally the silicon content of the metal from the blast furnaces is much higher than anticipated owing to unforeseen circumstances. Owing to the breakdown of the ladle crane in the Duplex plant mixer house, this high-silicon metal has had to be blown direct without passing through the mixer. Invariably such metal causes trouble in the open-hearth furnace.

The following examples (Table XIII) are taken from actual practice and show the percentage of residual silicon (and manganese) after the direct blowing of blast furnace metal which had a high silicon content. The analysis of the metal before and after blowing is given, together with the analysis of the slag taken from the converter ladle after the blow. In each case a single or a double 'kicker' was blown for finishing a charge and, after pouring the blown metal into the open-hearth, considerable difficulty was experienced in the elimination of phosphorus from the bath; while in the first two cases a rail steel was being attempted but, owing to the phosphorus not being satisfactorily eliminated by the time the carbon was right for tapping, the charge had to be worked down with iron ore and a tin-bar steel made instead, with consequent loss of time.

Table XIII.—Analyses of converter slags after blowing high-silicon metal

Analysis of blast furnace metal			Analysis of converter metal after blow			Remarks	Analysis of converter slag after blow				
C	Mn	Si	C	Mn	Si		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO
4.08	0.72	2.25	{ 2.74 2.60 }	0.28	0.456	'Double-kicker' for rail steel; two blows in one ladle	{ 61.47 62.20 }	4.07	3.85	10.11	17.82
4.13	0.84	2.06		0.30	0.583						
			{ 2.78 2.99 }	0.32	0.608	do.	{ 60.84 59.72 }	3.28	3.57	9.88	18.52
4.05	0.68	2.16		0.29	0.547						
			{ 1.33 1.28 }	0.21	0.442	'Single-kicker' for mild (structural) steel	{ 60.37 59.66 }	3.55	4.19	10.54	18.37
4.03	0.77	1.88		0.19	0.419						
			{ 1.12 1.09 }	0.17	0.467	'Single-kicker' for soft (tin-bar) steel	{ 17.74 19.08 }	4.86	3.90	10.35	17.74
4.08	0.56	2.10		0.19	0.405						
3.98	0.86	1.88				do.		4.27	3.01	10.58	19.86

The difficulty in eliminating phosphorus from the open-hearth bath was evidently due to the high percentage of residual silicon in the blown metal, together with the excessively high temperature generated in the metal during the blow by the combustion of so much silicon, the metal having been insufficiently cooled before being charged into the open-hearth furnace. It will be observed that all the slags are highly silicious and such slags cause the formation of 'salamanders' or 'kidneys' in the converters, to which further reference is made on page 381.

A low silicon content of the mixer metal will, of course, decrease the duration of the blow, but insufficient heat would be generated by the combustion of the silicon, with the result that the yield would suffer on account of the considerable loss which would take place owing to the formation of skulls in the converters, ladles, and furnace pouring chutes.

A high manganese content of the mixer metal increases the yield by combining with more silica and thus decreasing the requirements of the remaining silica for iron oxide; but at the same time the excess of MnO formed in the slag is liable to attack the vessel bottom and lining, particularly if the silicon in the metal is low, in which case the SiO_2 produced by oxidation will be insufficient to satisfy the demands of the MnO to form a silicate of manganese slag, and therefore the deficiency is supplied by the silica lining.

Although the silicates have here been dealt with as being monosilicates (1 part oxygen in the base to 1 part oxygen in the acid), as which it is generally agreed they mostly exist, it is possible that subsilicates (2 parts oxygen in the base to 1 part oxygen in the acid) and bisilicates (1 part oxygen in the base to 2 parts oxygen in the acid) are also present in the slag. The fact that the silicious lining of the converter is attacked whenever the manganese content of the metal which is being blown is higher than the silicon content seems to indicate that these two elements also form a silicate in the slag such as MnSi_2O_5 ; for, if all the manganese and silicon existed as the monosilicate, Mn_2SiO_4 , there should be no fluxing reaction with the silica lining until the manganese content of the metal was about four times the silicon content. When the manganese content is too high, the metal is also liable to 'slop' very badly during blowing, that is, to be ejected in considerable

quantities out of the converter mouth, thus causing wastage, and if this slopping is excessive it becomes difficult for the steel-blower to judge the progress of the blow, and it is necessary for him to reduce the pressure of the air blast to keep down the slopping as much as possible—a practice which is detrimental to the life of the tuyeres. This 'slopping' of the metal is caused by the slag becoming too thin or mobile in the converter by the introduction of such bases as CaO and MgO from the blast-furnace or mixer slag, or the formation of MnO in the converter from a high manganese content of the metal which is being blown. The slag in the converter, on account of its increased fluidity, is then incapable of withstanding the pressure of the air blast, with the result that some of the slag and a considerable quantity of the metal are ejected from the vessel as soon as CO is being rapidly evolved during blowing. On the other hand, a highly silicious slag is very viscous and acts as a blanket for the metal during blowing, so that the pressure of the air blast is insufficient to eject the metal through the slag and out of the converter during the evolution of CO . It is only the formation of a silicious slag at the commencement of the blow before the carbon is oxidized that enables the metal to be blown at all, for if the carbon were oxidized first, 'slopping' would immediately commence, with the result that most of the metal would be ejected by the end of the blow. In support of the statement that it is on account of the converter slag becoming too basic, and consequently too fluid, that slopping takes place, the latter can be prevented if sufficient ferro-silicon is added in the converter before commencing to blow metal which is giving trouble owing to slopping, the silicon from the alloy, of course, being oxidized to silica, which enters the slag. As stated above, in addition to a high manganese content of the metal being the cause of slopping, the introduction of basic slag containing CaO and MgO into the converter with the metal has the same effect. Although care is exercised to keep the blast furnace basic slag from entering the hot metal mixer when pouring in molten pig iron from the blast furnaces, some slag inevitably finds its way into the mixer. If the latter is maintained at too high a temperature, the slag in the mixer becomes very mobile so that it is then very difficult to hold it back with rakes to prevent it from

entering the converter transfer ladle and being subsequently poured into the converter with the molten metal. The following are analyses of two samples of converter slag from two blows (a) and (b) during which excessive 'slopping' occurred from different causes:

	(a)	(b)
SiO ₂	48.22	48.10
Al ₂ O ₃	4.47	5.57
Fe ₂ O ₃	2.89	4.80
FeO.....	17.36	15.71
MnO.....	23.53	13.27
CaO.....	1.24	9.90
MgO.....	0.33	2.20
TiO ₂	1.61	trace
P ₂ O ₅	0.037	trace
S.....	0.048	nil

(a) The 'slopping' in this case was due to the metal which was blown having a high manganese and low silicon content, *e.g.*, 1.28 per cent Mn and 0.56 per cent Si. This metal was obtained from 'C' blast furnace and was charged direct into the converter from the blast furnace ladle.

(b) In this case the 'slopping' was caused by the introduction of basic slag into the converter, the resultant converter slag being very fluid and brown in colour.

A low manganese content of the mixer metal, especially if the silicon content is high, brings about the formation in the converter of 'salamanders' or 'kidneys', as they are called. These consist of large accumulations of a very hard dark grey slag which adhere to the converter lining, and are extremely difficult to remove, while if they are allowed to collect they soon reduce considerably the capacity of the vessel. The probable cause of their formation is that the slag becomes very viscous with low MnO content, particularly if the percentage of SiO₂ is high owing to a high percentage of silicon having been present in the metal. While the blown metal is being poured into the ladle and the converter is in a more or less

horizontal position, the viscous slag on each side of the stream of metal in contact with the vessel lining becomes firmly attached thereto and steadily accumulates after each blow.

However, the composition of this slag becomes altered in some manner, possibly by becoming saturated with metal during pouring, for while the converter slag under such conditions is highly silicious with a fairly low iron content, the silica content of the 'salamander' is found to be considerably lower, while the iron content is correspondingly higher. The following are comparative analyses of a sample of salamander slag cut from the converter lining, and of the corresponding converter slag taken at the end of the blow:

	Salamander	Converter slag
SiO ₂	37.76	59.47
Al ₂ O ₃	6.45	6.28
Fe ₂ O ₃	0.87	1.55
FeO.....	33.96	12.51
MnO.....	14.85	14.67
CaO.....	1.44	1.20
MgO.....	0.33	0.27
TiO ₂	4.01	3.79
P ₂ O ₅	0.062	0.055
S.....	0.032	0.032

Occasionally this accumulation of salamander in the converters becomes very troublesome, and if the vessel cannot be spared in order to cut out some of it by the use of hammers and bars, an attempt is sometimes made to remove it as much as possible by fluxing. This is accomplished by adding some ferro-manganese in the converter and then pouring into the vessel a few tons of mixer metal and blowing it until it is all slagged. This is only done when the remainder of the lining is sufficiently thick to withstand the corrosion which takes place, and when the converter bottom is nearly played out. The following is the analysis of a sample of converter slag resulting from the complete blowing to slag of three tons of mixer metal containing 1.14 per cent Si and 0.76 per cent Mn,

to which 400 lb. of ferro-manganese containing 73.5 per cent Mn was added:

SiO ₂	29.50
Al ₂ O ₃	10.00
Fe ₂ O ₃	9.00
FeO.....	37.53
MnO.....	9.48
CaO.....	3.50
MgO.....	0.54
TiO ₂	0.58
P ₂ O ₅	0.24
SO ₃	0.054

As previously stated, an average weight of 22 tons of mixer metal is charged into the converters, so that the resultant weight of blown metal poured into the ladle to be conveyed to the open-hearth furnaces is approximately 20 tons.

Frequently two heats of blown metal are doubled into one ladle, and if they are low-carbon blows they are known as 'double-softs', or 'double-headers', whereas if they are high-carbon blows they are known as 'double-kickers'. Double-soft blows (0.10 per cent C) are used for all grades of open-hearth steel, whilst double-kickers are used for rail steel. The reason for these various blows is discussed later, in the Section dealing with the open-hearth process.

The converters are lined with mica schist, the analysis of which has been given on page 342. The stone is roughly cut so that the lining is approximately 20 in. to 24 in. in thickness. The length of time occupied in relining a vessel is about 30 hours. About the same period is taken up in drying, which is done by making a coke fire on the vessel and also directing a flame of coke-oven gas into it from a burner consisting of a pipe perforated with holes. After the lining has been thoroughly dried, the bottom containing the tuyeres is fitted on the vessel. These bottoms are prepared in the bottom house and contain 25 tuyeres, each tuyere being perforated with ten $\frac{5}{8}$ -in.-diameter holes. When making up a new bottom, an outside ring of mica schist about 18-in. thick is first of all placed round the shell. This stone lining comes into contact with the stone lining of the converter and is thus protected from the corrosion which the centre portion undergoes during blowing, so that this outside lining outlasts several relinings of the

centre portion. After the shell has been lined, the tuyeres are then placed into position through holes in the tuyere plate, and around the tuyeres is packed a mixture composed of ground silicious stone and clay, and in this mixture is tamped a considerable amount of broken silica bricks and firebricks discarded after open-hearth furnace and ladle repairs, while thirty-two 26 in. by 9 in. by $2\frac{1}{2}$ in. firebrick tiles (of the analysis given on page 345) are placed on end at the sides of the tuyeres.

About four hours are spent in making up a bottom, after which it is placed on a bogie and shunted into a drying oven heated by either coke-oven gas or coal, usually the former. The minimum time occupied in drying a bottom is 72 hours, the heat of the ovens being gradually increased during the first 24 hours until a temperature of about 900°F. (482°C.) is reached. This temperature is maintained until 60 hours have elapsed, after which it is gradually decreased during the next 12 hours, when the bottom is ready for taking out of the oven.

As soon as the bottom is required for one of the converters, it is removed from the drying oven and a ring of composition or mud about 3-in. thick placed round the outside of the bottom, which has to come into contact with the converter lining. This is done to make up the joint or shoulder when the bottom is connected to the vessel. After the shoulder mud has been put on it is coated with plumbago to prevent the mud from adhering to the vessel lining, and the bottom is then loaded on to a hydraulic jack car and shunted into position directly underneath the converter. These jack cars are fitted with a table to support the converter bottoms, and the table is lifted or lowered by means of a hydraulic ram. Below the converters, hydraulic pipes fitted with valves are provided for connecting up to the jack car pipes, through which water, under 500 lb. per square inch pressure, from the accumulator is allowed to flow to raise the table supporting the converter bottom. The table can be revolved on the ram so that the bottom can be turned into any desired position. As soon as the bottom has been lifted to its full height and turned into its correct position, it is fastened to the vessel, which has been

rotated into a vertical position in readiness, by means of twelve steel hangers and wedges, and the necessary pipe connection is made for the air blast. The shoulder mud is made only slightly damp and is squeezed when the bottom is lifted to its maximum height. If the joint at any time is wider than normal owing to the growth on the converter lining of salamander which cannot be removed without a considerable waste of time, then pieces of mica schist stone are rammed into the mud and extra mud plastered in the joint to make it secure.

Before commencing to blow on a newly lined bottom it is usual to blank off from 3 to 5 tuyeres according to the holding capacity of the vessel, which depends on the state of the lining with regard to the growth of salamander. The tuyeres blanked off are those at the bottom of the vessel when it is in a horizontal position for receiving the charge, so that metal is prevented from entering any of the holes of such tuyeres that may possibly come below the surface level of the metal charged. After the necessary number of tuyeres have been blanked off and the shoulder joint properly made, the bottom plate covering the tuyeres is put on the converter bottom and fastened by means of twenty-four slotted pins and steel wedges, and the bottom is then ready for blowing a charge. This blanking of a few tuyeres before commencing to blow on a relined bottom, instead of leaving out altogether the tuyeres not required, is rendered necessary owing to the air pipes being situated on opposite sides of each vessel. A bottom, therefore, required for one vessel has to be turned the opposite way round for the other, and as it has been found advisable to make up all bottoms to suit either converter, the practice of making them all up with the full 25 tuyeres and blanking off those not required has been adopted.

Upon starting to blow, a small test charge of about five tons is blown for a period of about two minutes in order to test the shoulder joint for leaks. If the joint is satisfactory then the remaining 17 tons or so is poured into the vessel and the blow continued.

Periodically the bottom tuyere covering plate is removed for the inspection of the tuyeres, and if any are defective they

are blanked off. The blanking of tuyeres is accomplished by cutting out a portion of each defective tuyere, plastering up with mud, and then fastening a circular plate over the tuyere end by means of a bar and T-screw which fit in a pair of lugs cast in the tuyere plate. One pair of these lugs is provided on the tuyere plate for each tuyere.

A bottom is condemned and taken off for relining as soon as it is observed that the shortest tuyeres have been reduced to a length of 13 inches. For the purpose of removing a worn out bottom, a jack car is shunted beneath the vessel, the necessary hydraulic connections made, and the table lifted until it is in contact with the converter bottom. The wedges are then knocked out of the hangers, and the old bottom is lowered down on the jack car table, after which the car is shunted to the bottom house, where the bottom is taken off the car, cleaned of all the old tuyeres and packing mud, and is then placed over a shallow pit for relining. The time occupied in changing a bottom is approximately one hour from blow to blow. With the present electrical equipment, it is only possible to blow one converter at a time; therefore it is arranged that one vessel has a newly lined bottom when the bottom of the other vessel is about half played out.

As previously recorded on page 347, two bottoms are made up with American tuyeres, which have an average life of 33 blows, to one with Indian tuyeres, usually Burn & Company's or 'Reliance', which have an average life of 27 and 24 blows respectively. The average taken over a period of one month for all makes of tuyeres was 29 blows. The highest number of blows obtained on one bottom with American 'Climax' tuyeres is 52, and with Indian tuyeres 40.

The average life of the converter lining is about six months, but the vessels are usually down from about 5 p.m. on Saturday to 6 a.m. on Sunday each week-end, when any necessary repairs to the lining are executed. If the lining is worn too much in places it is patched with mud and mica schist stone, whilst if large 'kidneys' have formed they are removed by the use of hammers and bars.

The composition of the various mixtures used for relining the converter bottoms, making up the shoulder joints, patching the vessel lining, and for jointing material for relining the vessels with mica schist stone, are given in Table XIV below:

Table XIV.—Composition of silicious mud used for the bottoms and linings of the Bessemer converters

Material used	Lining for converter bottoms		Converter shoulder mud	Converter patching mud, and jointing mud for mica schist lining
	When American tuyeres used	When Indian tuyeres used		
Mica schist.....	24	32	..	30
Ganister.....	36	20	30	15
Old silica brick.....	24	20	30	20
White clay.....	12	14	30	25
Black clay.....	4	14	10	10
Coke dust.....	2	2	1	2

The materials are crushed in the dry pan and mixed together in the above proportions by weight and ground into mud with the admixture of water in the wet pan in the bottom house. If there is a shortage of old silica brick, the deficiency is made up with mica schist and ganister.

As at present only one converter can be blown at a time, the number of blows possible in 24 hours is limited to about 96, that is, four blows per hour or 32 blows per 8-hour shift, after allowing time for the transfer of mixer metal to the converters and pouring out the blown metal into the ladle for the open-hearth furnaces, in addition to the blowing time. The record number of blows obtained to-date during one 8-hour shift is 32, and in 24 hours, 76, when 14 heats were tapped from the two Duplex open-hearth furnaces from 6 a.m. November 24th, to 6 a.m. November 25th, 1926.

The catching of the carbon near the desired percentage when blowing 'kickers' is not very difficult for experienced steel-blowers, and at the Duplex plant of the Tata Company the steel-blowers usually keep within 0.25 per cent of the carbon required for all high-carbon blows.

(d) *Open-Hearth Tilting Furnaces to Casting House*

It is chiefly the high phosphorus content of the Bessemer blown metal which makes its subsequent refinement necessary in the basic open-hearth furnace, and to effect the elimination of phosphorus to the desired extent, and at the same time obtain a sufficiently high tapping temperature, the following procedure is adopted.

A few minutes before a furnace is ready for tapping, orders are given to the Bessemer department for the requisite number of blows for the next charge. At the same time the percentage of carbon required for each blow is specified, depending upon the grade of steel to be produced.

After a furnace is tapped from a previous heat and rolled back into its normal position, there is approximately 40 tons of molten steel left in the bath, for although 'A' furnace has normally a capacity of 200 tons, and 'B' furnace 250 tons, it has been found to be more economical to work them with maximum charges of about 150 tons, from which about 110 tons is poured at each tap.

As the average weight of each heat of blown metal from the Bessemer converters is approximately 20 tons, it is therefore necessary to charge in the open-hearth furnace five and six blows, that is, about 100 and 120 tons, alternately, in order to replace the metal tapped out and maintain the total weight of metal in the bath fairly constant and as nearly as possible to the 150-ton maximum charge mentioned.

Particulars of the blows normally required for various grades of steel are given in Table XV.

Table XV.—Particulars of Bessemer blows required for various grades of basic open-hearth steel

No. of blow	Tin-bar steel (0.10 to 0.14%C)			Structural steel (0.22 to 0.26%C)			Rail steel (0.55 to 0.65%C)		
	Blow ordered	Carbon required in blow	Remarks	Blow ordered	Carbon required in blow	Remarks	Blow ordered	Carbon required in blow	Remarks
1	Double-soft	0.10	Double-header in one ladle	Double-soft	0.10	Double header in one ladle	Double-soft	0.10	Double-header in one ladle
2		0.10			0.10			0.10	
3	Single-soft	0.10		Single-soft	0.10		Single-kicker	1.00	
4	do.	0.10		do.	0.10		Double-kicker	2.50 to 2.75	Double-header in one ladle
5	Single-kicker	1.00		Single-kicker	1.50 to 1.75			2.50 to 2.75	

If a six-blow charge is required for the open-hearth furnace, then an extra single soft heat of blown metal in addition to the above is charged before the 'single-kicker' for each grade of steel.

When the furnace is rolled back after tapping a heat, it is tilted a little towards the charging side before being rolled into its normal position, in order to drain out the taphole, which is subsequently made up with lime (calcined limestone). While the furnace is tilted during tapping, burned magnesite (mixed with 20 per cent basic slag) is thrown on the skew-back and tapping side wall, and, directly the furnace is in its normal position, the furnace men effect any necessary repairs to the side walls and banks of the furnace, burned magnesite being thrown on the tapping side wall and burned dolomite used round the breasts and along the slag line of the hearth where corrosion has been most rapid. When these repairs have been done, the flame, which was turned down while the furnace was being tapped, is now fully turned on, and a quantity of lime (calcined limestone) and mill scale is charged, usually two or three boxes of each being added to the bath, each box containing 1,000 lb. of lime or scale, and a highly basic and oxidizing slag is thus formed.

Meanwhile, the first two heats of Bessemer metal ordered have been blown and poured into one ladle and are known as a 'double-soft' or 'double-header', the weight of blown metal in the ladle being approximately 40 tons and the carbon content about 0.10 per cent. This metal, after being cleaned as much as possible of its silicious slag by pouring the latter into a slag pan, is conveyed to the open-hearth furnace and poured through one of the side doorways, usually No. 2 doorway being employed for the first ladle of metal.

The usual length of time occupied between the furnace tapping and charging is 25 minutes, about 10 minutes being taken up in pouring out the metal during tapping, and 15 minutes in fettling the furnace.

More lime and scale are now charged, the amount depending on the grade of steel to be produced. The subsequent charges of blown metal introduced into the open-hearth bath also depend on the grade of steel, as will be observed from the particulars of various charges given on page 389.

(1) If a soft or a mild steel (tin-bar or structural grade) is required, then either two or three more single soft blows (0.10 per cent C), depending on the weight of the metal in the open-hearth bath, are poured into the furnace, each of these charges weighing about 20 tons. The second charge of soft blown metal is usually poured into the furnace through No. 4 doorway, and subsequent soft blows through No. 2 and No. 4 doorways alternately. The metal is distributed in this manner in order to prevent the undue wearing of any one breast.

After each charge of this low-carbon Bessemer metal, more lime is charged accompanied by scale at first until an average of about 7,000 lb. of the latter has been used. Lime is then added by itself according to the requirements of the furnace bath as indicated by the appearance of the slag, the average amount used being about 13,000 lb. for tin-bar steel (0.030 to 0.070 per cent P) and 16,000 lb. for structural steel (0.050 per cent maximum P). Occasionally, instead of two single soft blows being charged into the furnace after the first 'double-header', a second 'double-header' is charged, the two heats being blown and poured into one ladle in order to save a journey of the ladle crane, but single soft-blows are preferred after the first 'double-header', as lime can be more rapidly worked into the slag between the single blows.

The final charge of blown metal is known as the 'single-kicker', and consists of 20 tons of metal containing about 1 per cent carbon for soft steels, and from $1\frac{1}{4}$ to $1\frac{3}{4}$ per cent carbon for mild steels, depending on the carbon required in the finished steel.

As only one converter can be blown at one time with the present electrical equipment, the normal length of time occupied between each charge of Bessemer metal is from 15 to 20 minutes, so that five blows totalling 100 tons are charged in 45 minutes to one hour, and six blows totalling 120 tons in 1 hour to 1 hour 20 minutes.

Immediately the final blow of carbon-bearing metal is introduced into the open-hearth bath, the highly oxidizing conditions which prevail cause the very rapid elimination of carbon as CO, thus:



This carbon monoxide gas passing up through the metal and slag causes severe agitation of the bath, so that a most violent 'boil' is produced. The centre doorway is always employed for the introduction of a high-carbon blow or 'kicker', and as soon as this 'kicker' is completely poured into the furnace, the reaction becomes extremely vigorous and the slag, as a result, increases in volume by its admixture with the evolved gas bubbles passing through it, and pours (or is 'kicked') out of the furnace side doorways Nos. 2 and 4, the doors of which have been previously raised to allow the slag to flow out during the 'kick', into the slag hole at the charging side of the furnace, from where the slag is subsequently removed to the slag dump. To enable the slag to be removed more expeditiously, slag thimbles on bogies situated on ground level will shortly be employed for catching the slag as it flows through the furnace doorways, so that it can be shunted directly to the slag dump without handling.

While the charge is thus violently boiled in the presence of a highly basic oxidizing slag, the phosphorus in the metal is rapidly oxidized to anhydrous phosphoric acid, P_2O_5 , which combines with the lime present to form calcium phosphate, $Ca_4P_2O_9$, and the slag which overflows through Nos. 2 and 4 doorways contains a considerable amount of this P_2O_5 .

The vigorous boiling continues for a few minutes until almost all the carbon is removed, when the violence of the reaction diminishes, and the bath loses oxygen more slowly until finally the metal becomes quiet.

When this state is reached, a sample of metal is taken from the bath in a spoon and poured into a small rectangular cast iron mould, the inner dimensions of which are 6 in. by 2 in. at the top and $5\frac{1}{2}$ in. by $1\frac{1}{2}$ in. at the bottom, the mould being 2-in. deep. The sample is allowed to solidify, then quenched in water until cold, and broken for the fracture to be examined. From the appearance of this fracture the condition of the metal in the bath is judged, and further steps taken as indicated by the sample.

If the carbon after the 'boil' is judged to be sufficiently low, a similar sample, or half the fractured sample is drilled for analysis, the carbon, manganese, and phosphorus being determined. If the carbon in the bath is higher than required

after the 'kick', and the bath is sufficiently hot, iron ore is added until the fracture of a sample indicates that the desired carbon is reached. For soft steels, such as for sheet-bar and tin-bar, the bath is allowed to boil until the carbon is not above 0.08 per cent, iron ore or scale being added if necessary to speed up the oxidation. For mild steels, such as for structural steel to finish 0.22 to 0.26 per cent carbon, it is desired to catch the carbon at about 0.18 per cent.

It is desirable that the phosphorus content of the metal before tapping a mild steel heat (specification 0.050 per cent maximum P) should not exceed 0.028 per cent to allow sufficiently for rephosphorization, which frequently occurs owing to the return of some phosphorus from the slag to the metal in the finishing stages, and also on account of the addition of phosphorus in the ferro-manganese. For tin-bar heats (specification 0.030 to 0.070 per cent P) the phosphorus in the bath may be as high as 0.045 per cent before tapping.

If, however, the analysis shows that there is too great a quantity of phosphorus remaining in the metal after the 'kick', it is necessary to work the charge down until the carbon is not above 0.08 per cent. More lime is then added, followed by a box of basic pig iron (3,500 lb.) to cause a further reaction. Sometimes when the phosphorus after the 'kick' is much higher than anticipated, another 'kicker' of, say, 10 to 20 tons is added instead of pig iron, providing there is room in the furnace bath for the extra blow. In this case one soft blow less is charged for the next heat.

As soon as the bath has assumed its proper composition, the metal is tested for heat by rabbling the bath with a 1¼-in.-square steel rod. If the metal is judged to be sufficiently hot, which is indicated by a clean cut rod with no signs of adhering metal, a box of ferro-manganese (1,800 lb.) is added to the bath for a mild (structural) steel heat and the furnace tapped eight minutes later. For soft steels, such as for sheet and tin-bar, no ferro-manganese is added to the bath. Directly the furnace is ready for tapping, the taphole is opened by clearing out the lime with which it was closed, and, as soon as this has been done, the taphole is plugged with about four rolls of wet sacking. This procedure is followed in order to ensure the tapping of the metal before the slag, for it is very important

that the latter be held back until the end of the tap, otherwise a very heavy loss of manganese would result. Furthermore, a big jump in phosphorus may occur, and it would also be impossible to recarburize the metal satisfactorily.

The furnace is then tilted for pouring. Before the sacking is burned through, the slag is high up the tapping side wall, well above the taphole, so that clean metal comes from the furnace first. The alloys are then added to the ladle, and also coke dust for recarburizing when necessary.

For mild steels, 1,800 lb. of low-phosphorus ferro-manganese (averaging 73.5 per cent Mn) is added to the furnace bath as previously mentioned, and the remainder, the weight of which depends on the Mn content of the metal in the bath, is added to the ladle together with 180 lb. of ferro-silicon (75-80 per cent Si), and coke dust if required. The amount of low-phosphorus ferro-manganese (73.5 per cent Mn) required in the ladle in addition to that added to the furnace bath for mild steels, the Mn specification for which is 0.65 to 0.70 per cent, is 1,400 lb. with 0.10 per cent Mn in the bath.

For tin- and sheet-bar steel, the Mn specification for which is 0.40 to 0.60 per cent, all the ferro-manganese is added to the ladle, 2,240 lb. of low-phosphorus ferro-manganese (averaging 73.5 per cent Mn) or 2,495 lb. of high-phosphorus ferro-manganese (averaging 66.0 per cent Mn) being required with 0.10 per cent Mn in the bath. If the bath is very low in phosphorus, the high-phosphorus alloy is used, whereas if the phosphorus in the bath is sufficiently high, then the low-phosphorus alloy is employed. For these low-carbon steels, 360 lb. of ferro-silicon is added in the ladle.

The metal from the furnace is poured until the ladle is filled within approximately four inches from the top, when the furnace is rolled back until sufficient slag is tapped to just cover the surface of the metal, following which the furnace is rolled into its normal position after tilting it a little towards the charging side to drain out the taphole.

The normal time occupied in making a tin-bar heat of five blows is 1 hr. 50 min., and for a six-blow charge, 2 hr. 10 min., while for a mild (structural) steel heat of five or six blows 2 hours and 2 hr. 20 min., respectively, are occupied from commencing to charge to tapping the furnace. As previously

stated, the normal time between tapping and recharging is 25 minutes. Soft and mild heats are frequently made in much less time in very favourable circumstances, for on several occasions tin-bar heats have been made in 1 hour 10 minutes and mild steel heats in 1 hour 20 minutes, the record time for a five-blow heat for tin-bar steel being 55 minutes (Cast 9449B); while on the other hand, difficulty in eliminating phosphorus to the desired extent, lack of heat in the furnace bath, converter delays, breakdown of equipment, etc., will, of course, cause the above normal times to be exceeded. Tin-bar steel is occasionally made without a 'kicker' at all, for it sometimes happens that, after the four or five soft-blows have been charged into the open-hearth furnace, a delay occurs at the converters before the 'kicker' can be blown. In such cases, if the delay is likely to be of too long a duration, a reaction is caused in the furnace bath by the addition of a box of pig iron (3,500 lb.) and, providing the phosphorus is sufficiently low and the metal hot enough, the furnace is tapped and an extra blow charged for the next heat.

(2) If a rail heat is being made — the specification for which is: C, 0.55 to 0.65 per cent; Mn, 0.65 to 0.85 per cent; P and S, 0.050 per cent maximum — then a different procedure is adopted and, as far as the author is aware, the method followed at the Duplex plant of the Tata Company for making rail steel is the only one of its kind in the world. After the first charge of about 40 tons of soft blown metal of about 0.10 per cent carbon, preceded by the addition of about 3,000 lb. each of lime and scale, a further soft blow is charged only in the event of a six-blow charge of about 120 tons being required to fill the furnace. If only a five-blow charge of about 100 tons is required, then lime and scale together are added to the bath until a total of about 7,000 lb. of the latter has been charged, after which lime is added alone.

When following one rail heat with another, it is sometimes necessary to add some iron ore to the furnace bath in order to speed up the oxidation of the carbon when the soft-blows do not sufficiently dilute the percentage of carbon left in the bath from the previous rail heat, for it is essential that the

carbon in the bath be not more than 0.10 per cent before a 'kicker' is charged.

When the lime is almost completely worked into the slag and the carbon in the bath is sufficiently low, a 'single-kicker' of about 20 tons of partially blown metal to contain about 1 per cent carbon is ordered from the Bessemer department. This blow is usually charged into the furnace about $1\frac{1}{4}$ hours after the last soft blow, during which time a further addition of about 4,000 lb. of scale and 10,000 lb. of lime have been added to the bath. The 'single-kicker' is poured into the furnace through the middle doorway (No. 3) and the violent reaction which ensues causes the ejection of slag through Nos. 2 and 4 doorways. About 6,000 lb. more lime is added, and after the reaction has subsided samples of metal are taken and fractured for examination, and one sample is sent to the laboratory to be drilled for phosphorus determination. The bath is allowed to boil down until only 0.05 per cent to 0.10 per cent carbon remains in the metal before the final blows are charged, the elimination of this element being speeded up by the addition of iron ore if necessary. It is absolutely essential when making rail steel that the phosphorus in the metal is not more than 0.028 per cent before the final 'kicker' is added, and if the analysis shows that it is more than this, a box of pig iron (3,500 lb.) is added together with more lime and scale in order to cause a further reaction in the bath and effect the elimination of more phosphorus. This procedure is repeated if necessary.

Directly the percentage of phosphorus, and also of carbon, in the metal is sufficiently low, the final blows are ordered from the Bessemer department. These consist of two heats of partially blown metal which are poured into one ladle and are known as the 'double-kicker', the blow being stopped and the vessel turned down when the steel-blower judges the carbon in the metal to be from 2.50 to 2.75 per cent. Each heat is of about 20 tons weight, so that the weight of metal poured into the furnace is about 40 tons.

As it is much more difficult to ensure the elimination of sufficient phosphorus, and as its reduction from the slag is more likely when there is much carbon present in the bath, the average amount of lime used for rail steel heats is greater

than for soft or mild steels, being about 19,000 lb., all of which is usually added before the 'double-kicker' is poured into the furnace. The usual time occupied between the single and double-kicker is about $1\frac{1}{4}$ hours. The introduction of the very high-carbon double-kicker into the very low-carbon bath through the middle doorway (No. 3), again causes the vigorous ejection of slag through Nos. 2 and 4 doorways, the reaction this time being much more violent than that obtained after the single-kicker. This violent reaction continues for a few minutes, after which the bath gradually quietens down. Samples are then taken, quenched, and broken for inspection, and directly it is seen that the bath has settled down to a steady boil, which it usually does in about 20 to 25 minutes after the double-kicker was charged, a sample is drilled for the determination of carbon, manganese, and phosphorus.

The bath before the double-kicker contained about 110 tons of metal of 0.05 per cent to 0.10 per cent carbon, and the addition of 40 tons of metal in the double-kicker, containing about 2.50 to 2.75 per cent carbon, theoretically increases the carbon in the furnace bath to 0.75 per cent, but under normal conditions the result of the first carbon determination is usually about 0.65 per cent with about 0.025 per cent phosphorus and 0.10 to 0.15 per cent manganese.

Samples are periodically drawn from the furnace bath and are quenched and fractured for examination, one half being drilled for carbon determination, while every alternate sample is analyzed for phosphorus and manganese. Any noticeable increase in the manganese content is viewed with suspicion, for if this element is being thus reduced from the slag to the metal it is an infallible sign that the slag is in an unsatisfactory condition and that, although the phosphorus content as shown by analysis may be sufficiently low when the carbon is right for tapping, there will be a big jump in the percentage of phosphorus, either before tapping the furnace (the rise of phosphorus occurring usually after the addition of ferro-manganese to the bath), or during tapping, while the steel is being poured from the furnace into the ladle. In the event of a steady rise of manganese occurring, the manufacture of a rail steel (the P specification for which is 0.05 per cent maximum) is not attempted, but iron ore is added and a mild or soft steel made instead, as it is much easier to eliminate the phosphorus with a low-carbon content of the metal.

Besides the ordinary oblong sample which is fractured, another kind of sample is taken for rail heats, the metal being poured from a spoon into a circular mould about $1\frac{1}{2}$ in. diameter by 12 in. long, made in two halves, and, from the manner in which the steel behaves as it solidifies in the mould, the carbon can be very accurately judged, especially between 0.60 and 0.40 per cent. After solidifying, about 4 in. of the bottom part of this round sample is cut off with a sett, flattened down with a hammer, quenched in water, and drilled for analysis.

For rail steel, the carbon specification for which is 0.55 to 0.65 per cent, it is desirable to catch the carbon during the boil at about 0.54 per cent, and as soon as the analysis of the metal shows that this content is being approached and that the percentage of phosphorus in the bath is sufficiently low, that is, below 0.028 per cent (above which a rail steel is not attempted), and also that the manganese content has not increased to any serious extent, a final sample is sent for carbon determination and a box of low-phosphorus ferro-manganese (1,800 lb. containing 73.5 per cent Mn) added to the furnace bath.

The metal is, of course, periodically tested for heat by rabbling the bath with a steel bar as previously stated.

Fifteen minutes after the addition of ferro-manganese the furnace is tapped as before described. In the meantime, the final carbon result is obtained, which is rapidly determined by the volumetric combustion method, and if the carbon is below 0.54 per cent the deficiency is made up by the addition of 40 lb. of coke dust for each 0.01 per cent carbon required. The remainder of the ferro-manganese required is added to the ladle, 1,680 lb. being necessary with 0.10 per cent Mn in the furnace bath, and 80 lb. of ferro-silicon (75 to 80 per cent) is also added in the ladle.

The normal time occupied between the addition of the 'double-kicker' and tapping the furnace is about $1\frac{1}{2}$ hours, and the total time taken by a normal five-blow charge for rail steel is about 4 hours, and by a six-blow charge about 4 hr. 20 min., from commencing to charge to tapping. The record time for a five-blow rail heat is 2 hr. 35 min., which has been accomplished on several occasions.

To make the Duplex process clearer, particulars of actual charges for various grades of steel are given in Tables XVI, XVII, and XVIII (pp. 400 to 405).

Tin-bar and mild steel are usually made in one furnace during alternate weeks and the mill rolls changed accordingly, while the other furnace mostly makes rail steel.

Occasional departures from normal practice occur owing to various circumstances. On Saturdays, the top taphole (there being two tapholes as explained later) is cut down before the last heat for the week is tapped, and only a four-blow heat of 80 tons charged, consisting of two soft blows in one ladle, one single soft blow, and a 'single-kicker' of about 0.80 to 1.00 per cent carbon, so that after the last heat is tapped not more than 20 tons of metal is left in the furnace during the week end.

Only tin-bar steel is made with this last heat, which is usually tapped within $1\frac{1}{2}$ hours from commencing to charge, as the cutting down of the taphole frequently causes the slag to enter the ladle with the metal during tapping, with the result that a considerable rise in the phosphorus content of the steel usually occurs owing to a reaction between the metal and the slag in the ladle. Satisfactory recarburization with coke dust is, of course, impossible in these circumstances, so that, unless the phosphorus in the metal is very low and the carbon is caught at the right percentage, the production of a medium or higher carbon steel is impracticable.

Unlike the usual American practice, the Duplex open-hearth furnaces of the Tata Company are not drained out each week-end, and it is not until a furnace is to be shut down for a long repair which necessitates the cooling down of the furnace, or when the bottom requires repairing as indicated by a boiling up of the metal, that the furnace bottom is ever drained. It therefore frequently happens that a furnace is worked for many weeks without the bottom being seen, as the wearing of the bottom is so very slight.

Each furnace has two tapholes, about 15 in. apart, through both of which the steel will run down the furnace launder. However, the top taphole is the one which is normally used and the bottom of the launder is bricked up to suit this taphole. When it is desired to drain all the metal and slag out of the furnace, firebricks are removed from the bottom of the launder until the level of the bottom taphole is reached, and this taphole is then opened by means of a hammer and steel bars, and the

TABLE XVI.—PARTICULARS OF DUPLEX CHARGE FOR TIN-BAR STEEL
(Cast 6041 B)

Grade of steel	Time last heat tapped		Time from tapping to re-charging		Time com-menced charging hot metal		Time finished charging hot metal		Time furnace tapped		Duration of heat in furnace		Time ladle filled		Time com-menced casting		Time finished casting		Diam. of nozzle
	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	
Tin-bar...	0	50	0	40	1	30	2	10	3	00	1	30	3	10	3	13	3	35	1 3/4

Particulars of hot metal consumed

Analysis of mixer metal					Weight of mixer metal charged into converter, lb.	Carbon required in blown metal %	Period of blow				Duration of blow, in minutes	Blast pressure, lb. per sq. in.	Carbon in blown metal, from analysis %	Time blown metal charged into O.H. furnace		Weight of blown metal charged into O.H. furnace lb.	No. of doorway metal poured through
							Commenced		Finished					hr.	min.		
C %	Mn %	S %	P %	Si %			hr.	min.	hr.	min.							
4.08	0.70	0.036	0.338	1.28	51,520	0.10	0	35	0	50	15	22	0.11	1	30	96,320	2
"	"	"	"	"	54,320	0.10	0	54	1	08	14	22	0.14				
"	"	"	"	"	51,520	0.10	1	12	1	27	15	22	0.04	1	40	47,040	4
"	"	"	"	"	52,080	0.10	1	29	1	44	15	19	0.08	1	55	47,600	2
"	"	"	"	"	51,520	1.00	1	48	2	00	12	19	1.30	2	10	47,040	3
Total.....					260,960									Total.....		238,000	

Lime consumed			Mill scale consumed			Finishing additions			Ingots produced		Weight of skull in ladle lb.
hr.	Time		lb.	Time		lb.	Time		No.	Weight lb.	
	min.			hr.	min.		hr.	min.			
1	05		3,000	1	05	2,000	In	ladle		1,848	
1	15		2,000	1	15	2,000	"	"		360	
1	35		2,000	1	35	1,000	In	moulds	21	239,120	2,400
2	00		2,000							11	
2	10		2,000								
2	30		1,000								
Total.....			12,000	Total.....		5,000					

Analysis of O.H. bath samples						Specification for steel					Actual analysis of ladle samples							
Time	hr.	min.	C	Mn	S	P	Si	C	Mn	S	P	Si	No. of sample	C	Mn	S	P	Si
2	25		0.14	0.10		0.040		0.10 to 0.14	0.40 to 0.60	Max. }	0.030 to 0.070	0.040 to 0.080	1	0.14	0.55	0.045	0.055	0.066
2	45		0.09	0.11		0.035				0.050			2	0.14				
													3	0.13				

TABLE XVII.—PARTICULARS OF DUPLEX CHARGE FOR STRUCTURAL STEEL
(Cast 6635 B)

Grade of steel	Time last heat tapped		Time from tapping to re-charging		Time commenced charging hot metal		Time finished charging hot metal		Time furnace tapped		Duration of heat		Time ladle filled		Time commenced casting		Time finished casting		Diam. of nozzle in.
	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	
Structural	15	35	0	40	16	15	17	00	18	05	1	50	18	13	18	15	18	38	1 3/4

Particulars of hot metal consumed

Analysis of mixer metal					Weight of mixer metal charged into converter lb.	Carbon required in blown metal %	Period of blow			Duration of blow in minutes	Blast pressure lb. per sq. in.	Carbon in blown metal from analysis %	Time blown metal charged into O.H. furnace		Weight of blown metal charged into O.H. furnace lb.	No. of door-way metal poured through		
C %	Mn %	S %	P %	Si %			Commenced	Finished	hr.				min.	hr.			min.	
4.05	0.64	0.04	0.35	0.90	53,200	0.10		15	22	15	37	15	23	0.06	16	15	96,320	4
"	"	"	"	"	52,640	0.10		15	46	16	01	15	19	0.07	16	30	54,880	2
"	"	"	"	"	60,480	0.10		16	05	16	19	14	20	0.07	16	45	53,760	4
"	"	"	"	"	58,800	0.10		16	22	16	35	13	20	0.08	16	00	50,400	3
"	"	"	"	"	55,440	1.50 to 1.75		16	38	16	50	12	19	1.76	17			
Total.....					280,560	Total.....										255,360		

TABLE XVIII.—PARTICULARS OF DUPLEX CHARGE FOR RAIL STEEL

(Cast 6852B)

Grade of steel	Time last heat tapped		Time from tapping to re-charging		Time commenced charging hot metal		Time finished charging hot metal		Time furnace tapped		Duration of heat in furnace		Time ladle filled		Time commenced casting		Time finished casting		Diam. of nozzle in.
	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.	
Rail.....	16	35	0	35	17	10	20	20	21	30	4	20	21	42	21	45	22	06	1 3/4

Particulars of hot metal consumed																						
Analysis of mixer metal					Weight of mixer metal charged into converter lb.	Carbon required in blown metal %	Period of blow				Duration of blow in minutes	Blast pressure lb. per sq. in.	Carbon in blown metal from analysis %	Time blown metal charged into O.H. furnace		Weight of blown metal charged into O.H. furnace lb.	No. of door-way metal poured through					
							Commenced	Finished		hr.				min.								
C %	Mn %	S %	P %	Si %	4.00	0.60	0.035	0.340	1.38	54,880	0.10	16	23	16	35	12	23	0.09	17	10	100,800	2
"	"	"	"	"	"	"	"	"	"	55,440	0.10	16	39	16	50	11	23	0.06	18	20	44,240	4
"	"	"	"	"	"	"	"	"	"	47,600	0.10	17	33	18	05	13	20	0.10	18	40	48,720	3
"	"	"	"	"	"	"	"	"	"	53,200	1.00	18	22	18	32	10	19	0.96	18			
4.04	0.59	0.037	0.346	1.13	39,200	2.50	19	48	19	55	7	19	19	19	20	6	19	2.32	20		76,720	3
"	"	"	"	"	44,800	to 2.75	19	59	20	05		20						2.60				
Total.....					295,120	to 2.75													Total.....		270,480	

assistance of oxygen if necessary. The bottom taphole is so fixed that all the steel and slag can be drained out of the furnace whenever this taphole is opened, which, however, is only done when considered absolutely necessary.

It is the customary practice to burn out the flues to each furnace every two weeks, that is, every alternate week for each furnace. It is usually arranged each Saturday that the furnace, for which the flues require cleaning, taps its last heat for the week about noon, after which the gas is shut off, while the other furnace taps its last heat for the week about 6 p.m. The usual time spent in burning out the flues is about 4 hours, after which the gas is again put into the furnace.

Gas is kept in both furnaces throughout the week-end, during which period they are thoroughly fettled, both charging and tapping side walls being attended to, burned dolomite being used round the slag line of the hearth and on the breasts, while burned magnesite is employed for repairing the tapping side walls and skewback. The ports are also cleaned and repaired if necessary, and any other minor repairs effected as required.

It is also the practice to prepare a good slag during the week-end for starting the following week's campaign, and to the metal remaining in the bath after tapping the last heat on Saturday, periodical additions of burned lime and mill scale are made and melted down, and it is customary to also add several boxes of steel scrap. By the time the furnaces are charged, about 12,000 lb. of lime, 6,000 lb. of scale and 18,000 lb. of scrap have been added to each furnace bath.

At 6 a.m. on Sundays, metal is ordered from the Bessemer department and blowing is commenced. For the first charge seven blows totalling about 140 tons are ordered, and either tin-bar or structural steel made. Instead of the usual soft blows followed by a single-kicker for these steels, the first charge of blown metal is a single blow of about 0.40 to 0.60 per cent carbon to give a little action to the bath. This first blow of about 20 tons of metal is added about 6.20 a.m. in the first furnace to charge, and after the boil has subsided it is followed by a second blow of a similar weight and carbon content. After the second reaction is over and the boil has again subsided, three single soft blows, each of about 20 tons

and containing about 0.10 per cent carbon, are added one after the other. The sixth blow is a single-kicker of about 20 tons and 1.00 to 1.25 per cent carbon, but before this is added the bath is allowed to boil down until the carbon is only about 0.05 to 0.10 per cent. This blow is followed by the usual violent reaction and ejection of slag, and as soon as the bath has again boiled down to 0.05 to 0.10 per cent carbon, with the assistance of iron ore additions if necessary, and the bath is sufficiently hot, the seventh and final blow is charged. This also consists of a single-kicker of about 20 tons, the carbon in this blown metal being from 1.00 to 1.75 per cent, depending on the carbon required in the finished steel. The charge is then finished in the usual manner.

Between each blow, about 2,000 lb. of lime is added to the bath, so that besides the 12,000 lb. used in the preparation of the slag during the week-end in readiness for the first charge, a further 12,000 lb. is used during the working of the heat.

This first charge of the week usually takes about four hours from commencing to charge to tapping the furnace, while the second and succeeding charges are worked in the normal manner as previously described.

As both converters cannot be blown at the same time (a state of affairs which will be remedied at an early date), and fourteen blows are required to fill both furnaces, blown metal is charged alternately in each furnace, or as required by the condition of the bath, if both furnaces are ready for charging. Therefore, if the first furnace commences to charge at 6.20 a.m., the other furnace will take the next blow and thus commence to charge at 6.40 a.m. Similarly, this practice is followed throughout the week whenever both furnaces tap about the same time, in which case delays in filling up the furnaces with blown metal are inevitable.

Whenever a furnace is to be shut down for a lengthy repair, such as a general repair or a new roof, the bottom taphole is usually opened to drain out the steel when tapping the last heat, and a tin-bar or sheet-bar heat made with the steel. After the furnace has been repaired, the bath is thoroughly cleaned of all silicious material before the furnace is lighted up. When the furnace has been heated up sufficiently, it is thoroughly fettled, calcined dolomite being used for the banks,

and calcined magnesite for the bottom, tapping side wall and skewback, after which the procedure is as follows:

About 3,000 lb. each of lime and scale are charged and melted down, these additions being twice repeated at intervals until about 9,000 lb. of each have been charged, after which two additions of about 3,000 lb. of lime alone are made so that a very highly basic oxidizing slag is obtained. Metal is then ordered from the Bessemer department for the first charge, seven single blows of about 20 tons each being charged into the furnace as required, the percentage of carbon required for each blow being as follows: (1) 0.40 to 0.60; (2) 1.00 to 1.25; (3) 0.20 to 0.30; (4) 0.20 to 0.30; (5) 1.00 to 1.25; (6) 1.00 to 1.25; and (7) 1.00 to 1.75.

The bath is allowed to boil down to 0.05 to 0.10 per cent carbon after each blow before the next one is charged, and by this means the bath is gradually heated up. Between each blow, about 2,000 lb. of lime is added, making the total lime addition 12,000 lb. during the heat in addition to the 15,000 lb. added prior to the heat being charged. Either a tin-bar or mild (structural) steel is usually made from the first heat after a repair, the normal time taken from commencing to charge to tapping being from 5 to 6 hours.

Should it be impracticable to drain out the bath through the bottom taphole before shutting down a furnace for a repair, owing to a portion of the roof having fallen in and the bricks blocking this taphole, the top taphole is opened and cut down as much as possible and as much steel is tapped out as can be obtained, and the furnace then shut down with the remaining steel in the bath. After the repair, as many as possible of the old silica bricks are removed from the bath before lighting up the furnace. While the furnace is being heated, plenty of lime is added to the bath to combine with the silica inevitably left in the bath and so protect the hearth.

When the furnace is sufficiently hot, three or four high-carbon single-kickers of about 20 tons each and about 1.25 to 1.50 per cent carbon are charged at intervals, and lime and scale additions made between each blow. Each charge of blown metal is allowed to boil down as usual until the carbon is only 0.05 to 0.10 per cent before the next charge of metal is poured into the bath. In this manner the metal left in the

furnace before shutting down for repairs is melted and the bath heated up sufficiently. Care is taken not to have more weight of metal in the bath than can be tapped out into a ladle, the total weight therefore not exceeding 110 tons, and if this weight is being closely approached and the bath is short of heat, an addition of pig iron, usually one box containing 3,500 lb., is made and the bath allowed to boil down, this being repeated if necessary until the required heat is attained, to ensure a proper casting temperature. When the furnace is almost ready for tapping, the bottom taphole is opened and the furnace drained of all metal and slag. Three or four hours are usually occupied in opening this taphole and while this is being done, additions of pig iron are made at intervals to keep the bath in good condition. After tapping, the furnace is thoroughly fettled and charged up as just described.

From the preceding description of the Duplex process it will be observed that the most important reaction taking place in the open-hearth furnace is that of dephosphorization of the blown metal. For the successful elimination of phosphorus in the minimum amount of time it is necessary that the temperature of the furnace and composition of the slag are very carefully controlled. The necessity for this is that, while both phosphorus and carbon have a chemical affinity for oxygen and will combine with it, this affinity varies with the temperature, the oxygen preferably combining with phosphorus at lower temperatures and with the carbon at high temperatures. Therefore, with a very high temperature in the bath, it is possible to eliminate almost all of the carbon before phosphorus is oxidized to any great extent, while, on the other hand, if the temperature be maintained lower, the phosphorus will be eliminated before the carbon.

The latter condition is that which is aimed at, and to remove the phosphorus as quickly as possible and get the resultant calcium phosphate slag out of the furnace, the slag must of necessity be of a highly oxidizing character, for to satisfactorily eliminate the phosphorus from the metal it is essential that the latter take up a liberal amount of oxygen. If the phosphorus be removed after the carbon, the metal will contain large amounts of dissolved or combined oxygen, and will consequently be very wild unless this excess oxygen is

removed by the addition of pig iron to the bath before tapping, or by the addition of extra ferro-manganese and ferro-silicon in the ladle during tapping, or extra aluminium in the moulds during casting.

On the other hand, if the operation is carried out properly at a comparatively low temperature and the required highly oxidizing conditions are maintained in the furnace bath, the phosphorus will be rapidly oxidized before the carbon, so that some of the latter remains in the bath to combine with the excess oxygen and remove it as CO. Thus a much better 'killed' steel is obtained than in the former case, for, as in all other steel-making processes, it is necessary to get rid of any excess of oxygen from the metal before casting, and preferably before tapping the furnace, in order to produce a steel of good quality which must of necessity be oxygen-free as far as practicable.

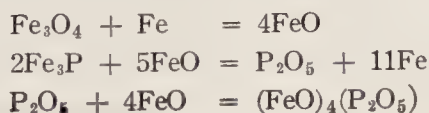
If the blown metal received from the Bessemer converters is exceptionally hot owing to there being too much silicon present in the mixer metal (or more often in blast furnace metal blown direct), and sufficient steaming and scrapping has not been done to cool down the temperature of the metal, and this extremely hot metal is poured into the open-hearth furnaces — especially if it is the final 'kicker' — the temperature may be so high that, although a good boil of the bath is obtained, it results in carbon being rapidly oxidized while the phosphorus is only slightly eliminated. Steps have, therefore, to be taken to eliminate the latter element and to reduce the temperature of the bath sufficiently, and it is sometimes necessary to turn down the flame or cut it off altogether and to open the furnace doors. If there is sufficient carbon present after the 'kick', a rapid feed of iron ore will produce the oxidizing conditions necessary for the removal of the phosphorus and at the same time help to cool down the bath. As soon as the carbon is removed, a further reaction is brought about by the addition of a box of pig iron (3,500 lb.). Lime is also added (usually two boxes of 1,000 lb. each), and, if necessary to thin down the slag, a few shovelfuls of fluorspar are added. Should the phosphorus be very high when the carbon is removed after the 'kick' and there is room in the bath, a further 'kicker' of about 10 to 20 tons weight and of about 1.00 to 1.25 per

cent carbon is ordered from the Bessemer department and poured into the furnace, instead of using cold pig iron; lime, of course, being added after the charge of hot blown metal.

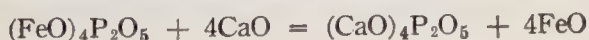
As the elimination of phosphorus is dependent on the prevalence of oxidizing conditions, there is always the danger of an excess of oxygen being present in the bath and when the heat is being poured, whenever proceedings have to be adopted to effect the removal of phosphorus after all the carbon has been oxidized.

The removal of phosphorus before carbon is, therefore, largely a question of temperature; but while the furnace should not be run too hot, it is essential that it be worked at a sufficiently high temperature to enable the slag to take up the lime as rapidly as possible. Temperature also plays an important part in another way, in that it controls the stability of the phosphoric acid in the slag; for with very high temperature there is always the danger of some phosphorus returning to the metal owing to the dissociation of the basic phosphate of lime, possibly by the reducing action of carbon in the metal, or of SiO_2 in the slag.

The oxidation and elimination of phosphorus depends on the prevalence of the following conditions: (a) a very basic slag; (b) a great excess of oxygen in the bath; and (c) a low temperature. The addition of mill scale to the metal brings about the oxidation of the phosphorus in the metal to P_2O_5 , which forms ferrous phosphate with FeO derived from the reduction of the Fe_3O_4 of the scale, thus:

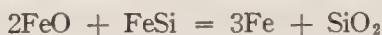


Ferrous phosphate, however, is very unstable at furnace temperatures, but the addition of an excess of lime, above that required to form calcium silicate with silica, converts ferrous phosphate into calcium phosphate, which is much more stable at normal furnace temperatures and only becomes unstable at very high temperatures. In the formation of calcium phosphate, the CaO added displaces FeO thus:

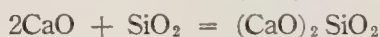
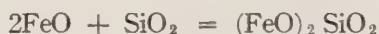


It is absolutely essential that as little acid slag as possible from the converter be allowed to enter the basic open-hearth furnace, on account of the fact that the phosphate content of the slag and the phosphorus content of the metal may be increased or diminished simply by changes in the concentration of SiO_2 . It is also found that, as SiO_2 decreases, the FeO increases, so that a low percentage of SiO_2 means a high percentage of FeO and consequently more complete dephosphorization. Further, the less silica the slag contains the more phosphorus it is able to contain.

Silica in the slag, obtained either from the oxidation of silicon from the metal according to the equation:



or directly from converter slag entering the bath during the charging of blown metal, or from the fusing of the silica structure of the furnace, forms ferrous silicate with FeO and calcium silicate with CaO , thus:



The addition of an excess of lime brings about the formation of calcium silicate by the displacement of FeO from the ferrous silicate, thus:



and the higher the temperature, the more ferrous silicate can be decomposed.

Calcium silicate is very stable, much more so than calcium phosphate, and so long as there is any uncombined silica in the slag any ferrous or calcium phosphate formed reacts with the silica according to the following equations:



thus setting free P_2O_5 and exposing it to possible reduction to phosphorus, which re-enters the metal as phosphide of iron.

On account of this reaction, phosphorus is not permanently oxidized until silicon is eliminated from the metal and all the silica of the slag is in the form of calcium silicate.

It is, therefore, important that the total amount of SiO_2 in the slag should only be such that P_2O_5 will not be again converted into the free state, otherwise it is very much liable to reduction.

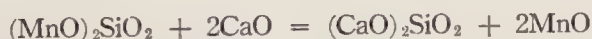
Whenever the slag is in such a condition that a reduction of P_2O_5 is about to take place, the reaction is generally preceded by a rise in the manganese content of the metal due to the reduction of MnO from the slag. Therefore, any noticeable rise in the percentage of manganese is a certain indication that a rise in phosphorus will follow.

This phenomenon is occasionally met with when making rail steel, where there is a fairly high percentage of carbon in the bath after the 'double-kicker'. As there is usually insufficient time in which to get the condition of the bath right by the time carbon is low enough for tapping, and the phosphorus is almost certain to finish too high for the specification if the metal is tapped with a rising Mn content — even though the P content is sufficiently low at the time — a rail heat is not attempted. Instead, iron ore additions are made and a lower carbon steel made, as it is much less difficult to control the phosphorus with a low carbon content of the bath.

Manganese is eliminated from the metal as manganese silicate and displaces iron from ferrous silicate, thus:



Lime is able to displace MnO from manganese silicate in the same manner that it does FeO from ferrous silicate:



The MnO thus liberated is liable to become reduced to Mn and re-enter the metal.

As previously stated in the paragraph on the Bessemer process (page 379), the various silicates have been treated as being monosilicates, whereas, it is possible that subsilicates and bisilicates are also present in the slag.

It occasionally happens that, after the boil has subsided, and the necessity arises for the addition of more lime to the bath on account of the phosphorus being insufficiently eliminated, the slag becomes very thick and viscous. When this occurs, it is necessary to thin down the slag by the addition of small quantities of fluorspar, the function of which is primarily to act as a fluxing agent so that the slag may carry a high CaO content at the same temperature of the bath. The addition of fluorspar also reduces the amount of lime required to combine with the P_2O_5 present, for when fluorspar is present the phosphate formed in the slag probably has the composition $CaF_2 (CaO)_3 P_2O_5$, *i.e.*, a fluor-apatite instead of a normal calcium phosphate, $(CaO)_4 P_2O_5$. The result of the above reactions is to give the slag a higher capacity for carrying phosphorus.

The addition of fluorspar to the slag also increases the power of the slag for absorbing sulphur from the metal. It is certain that fluorspar has distinct desulphurizing powers, but it is difficult to determine whether it is due to the fact that fluorspar confers fluidity upon the slag without appreciably decreasing its basicity or whether it is due to the following or a similar reaction:



When fluorspar is added to a basic open-hearth slag, the calcium fluoride is decomposed only to a certain limit which has been found in practice to be about 2 to $2\frac{1}{2}$ per cent. On first adding the fluorspar, silica passes off from the slag in the form of silicon fluoride, thus:



For the removal of sulphur from the metal, the slag must be very basic and fluid and maintained at a high temperature, thus differing from phosphorus, for the rapid elimination of which a comparatively low temperature is necessary. Sulphur is acted on much more slowly than phosphorus, but once the former element has been removed from the metal, it has not the tendency to return like phosphorus, and is therefore never reduced from the slag.

The slag must contain lime either in the free state or combined with sulphur, and the desulphurization takes place according to the following equation:



This reaction further indicates the necessity for the presence of carbon in the metal.

As the sulphur is removed from the metal to the slag it is driven off from the latter in some form of vapour, and the slag then takes up more sulphur from the metal.

Whenever the sulphur content of the mixer metal is running high, say over 0.050 per cent, owing to the percentage of this element being high in the pig iron from the blast furnaces, it is the practice to charge about 1,000 lb. of manganese ore into the open-hearth furnaces early in each heat.

It is well-known that manganese will desulphurize molten iron through the formation of manganese sulphide, for if there is an excess of manganese in the metal over the amount required to combine with the sulphur present, the latter element unites with manganese in preference to iron, thus:



Manganese sulphide, being only slightly soluble in the metal, rises and enters the slag, where it remains as such or is converted partly or wholly to calcium sulphide, especially when a great excess of CaO is present.

The greater the excess of manganese the lower will be the sulphur content of the metal, regardless of whether the sulphur was originally present as MnS or FeS.

It is, of course, always preferable that the sulphur content of the blast-furnace metal be below 0.045 per cent, for this element has a tendency to accompany the metal right through the iron and steel making processes and appear in the final product, and the more sulphur that reaches the open-hearth furnace the greater the expense of its removal. Therefore, the best way to ensure that the final steel will be sufficiently low in sulphur is to keep low the sulphur content of the original materials charged into the blast furnace, especially the coke, from which the larger part of the sulphur found in the metal is obtained.

It is necessary to emphasize the importance of the steel being tapped before the slag, for a big rise in phosphorus nearly always occurs owing to reactions taking place in the ladle when both metal and slag are tapped out together. If much slag is poured out with the metal, directly the furnace is tilted it will cause greater oxidation losses of manganese and silicon from the ferro-alloys added in the ladle, and the steel is, therefore, liable to be wild in the moulds; and furthermore, recarburization in the ladle with coke dust is impracticable.

As far as possible only sufficient slag to cover the surface of the steel and protect it from oxidation should be allowed to enter the ladle.

The weight of basic slag produced during the open-hearth process amounts to about $11\frac{3}{4}$ per cent of the weight of steel ingots. Table XIX gives average analyses of normal slag samples taken from the furnace bath immediately prior to the furnace being tapped:

Table XIX.—Average composition of Duplex basic open-hearth finishing slags

	Grade of steel		
	Tin-bar	Mild (structural)	Rail
	%	%	%
SiO ₂	14.37	14.81	15.64
Al ₂ O ₃	2.48	2.04	1.47
Fe ₂ O ₃	2.43	2.76	4.29
FeO.....	18.67	13.50	10.26
MnO.....	5.05	7.44	6.98
CaO.....	44.12	46.40	48.45
MgO.....	5.92	5.36	4.87
TiO ₂	0.66	0.70	0.63
P ₂ O ₅	6.18	6.92	7.43
S.....	0.068	0.096	0.112

For comparison with the average analyses of normal slags given above, analyses are given in Table XX of slag samples taken from various heats during the working of which trouble was experienced in eliminating phosphorus.

Table XX.—Composition of Duplex basic open-hearth slags, in the presence of which phosphorus has not been satisfactorily eliminated from the metal

Cast No.	Analysis of slag										Analysis of metal when slag sample taken		
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	CaO	MgO	TiO ₂	P ₂ O ₅	S	C	Mn	P
2825B	22.93	3.28	1.86	11.35	7.44	42.00	5.37	1.10	5.27	trace	.06	.06	.087
3638B	21.16	2.43	2.85	11.22	7.44	42.20	4.32	1.20	7.51	0.055	.07	.08	.071
*4816B	18.07	2.51	2.86	9.28	5.53	39.40	14.48	0.80	7.42	0.137	.62	.14	.075
5136B	18.53	2.34	2.00	8.36	7.63	49.00	4.85	1.31	6.18	0.041	.07	.10	.055
6245A	21.13	3.17	3.21	7.05	6.85	44.17	5.22	0.74	8.28	0.086	.06	.13	.070
6270A	22.27	1.94	2.74	9.14	6.21	43.28	6.86	1.02	6.49	0.077	.09	.14	.068
6657B	23.29	2.58	2.31	8.87	7.00	41.43	6.93	0.98	6.53	0.104	.09	.07	.110

*Intended for rail heat but changed to tin-bar on account of high phosphorus.

The necessity for proper control of the furnace temperature has already been referred to, and, as the best results are obtained when a fairly low temperature of the bath is maintained, the furnace men endeavour to so regulate the temperature of the metal prior to tapping that a thin bottom skull (weighing about 2,400 lb. or approximately 1 per cent of the weight of metal tapped into the ladle) is left in the ladle after casting the steel into ingots.

Should the temperature of the bath towards the end of the process be too low, as indicated by the appearance of a steel bar after immersing it in the metal for about one minute, a similar procedure is followed as when high-phosphorus is encountered, *i.e.*, a box of pig iron (3,500 lb.) is added to the bath to cause a reaction as soon as almost all the carbon has been oxidized from the metal, to enable the bath to acquire more heat during the boil. This is repeated if necessary, but if the bath is very cold a heat of high-carbon blown metal of 10 to 20 tons in weight and 1.50 to 2.00 per cent carbon is ordered from the Bessemer department and charged into the furnace instead of cold pig iron; that is, provided there is sufficient room in the furnace bath for this extra blow.

The average open-hearth losses amount to approximately $6\frac{1}{2}$ per cent of the metallic charge, which includes blown metal from the converters, and additions such as pig iron, scrap, ferro-alloys and the metallic contents of the mill scale and iron ore, and of any manganese ore charged. These additions average $4\frac{1}{2}$ per cent on the weight of blown metal charged. Therefore the loss on the actual weight of blown metal poured into the furnace calculated on the weight of steel poured out of the furnace into the ladle amounts to only about 2 per cent on account of the above metallic additions. The average yield of steel poured into the casting ladle from the open-hearth furnace is, therefore, about 88 per cent of the original weight of blast furnace metal.

With reference to the life of the furnace structure, the maximum number of heats obtained with a furnace roof was 877 heats on 'B' furnace. During this run, which lasted 25 weeks, only one minor repair was executed, a small patch being required near the centre of the roof after 745 heats.

At present both 'A' and 'B' furnace roofs are constructed with the centre portion consisting of panels and ribs and the end portions of bonded brickwork, as described on page 318; and a 1½-in.-wide joint was left between the centre section and the end bonded sections, with a further allowance of 4 in. for expansion at each end of the roof between the brickwork and the water-cooled chills.

The port blocks have been run for 877 heats without repairs, and the checker bricks for 1,605 heats. The average life of the furnace charging side walls is about 400 heats.

It may be of interest to include here analyses of samples of dust removed from the furnace checkers, and also of slag removed from the slag pockets (Table XXI).

Table XXI.—Composition of dust from Duplex open-hearth checkers and slag from slag pockets

	Dust from air checkers	Dust from gas checkers	Mixed slag from slag pockets
SiO ₂	8.16	11.12	54.56
Al ₂ O ₃	5.11	5.02	4.19
Cr ₂ O ₃	trace	3.05	...
Fe ₂ O ₃	20.00	20.29	4.57
FeO .....	...	...	11.86
MnO	1.86	1.67	2.24
CaO	42.75	45.60	18.80
MgO	8.32	8.83	1.87
TiO ₂	trace	trace	trace
P ₂ O ₅	2.75	3.60	1.65
SO ₃	11.53	1.17	0.04

The average length of time occupied on a general repair, which includes the building of a new roof, new charging side wall with door arches, new ramps, repairs to port blocks, uptakes, and slag pockets, and renewal of checker bricks, is eight days from the time the gas is shut off. Directly the repairs are completed a wood fire is lighted in the furnace hearth, and a coke fire in each slag pocket, from which the slag accumulated during the last run of the furnace is removed while the various repairs are being effected. The slag pockets are left open until the fires are well lighted, after which the respective bulkheads are built up, a hole about 18-in.-square being left in each bulkhead near ground level for the admission of air, and a smaller hole about 4 feet above ground level for the introduction of a tar burner. Tar and steam are then turned on and regulated to give a steady flame, by which means the regenerators are warmed up and in 36 hours are at a cherry-red heat. During this period, the melting chamber is gradually heated up by the wood fire in the hearth. Meanwhile, a tar burner is placed down each gas port and about 48 hours after the wood fire was lighted one of these tar burners is turned on and the melting chamber further heated by this means, the tar burners in each gas port being used alternately, thus reversing the direction of the flame at intervals. In about 18 hours after the tar burners were lighted, the melting chamber attains a cherry-red heat, following which producer gas is turned into the furnace. In a further 36 hours, the furnace is hot enough to be fettled, and in approximately 13 days from the time gas was shut off the furnace is ready for charging.

The tar burners are kept in the slag pockets until the regenerators are heated to their normal working temperature, which is about 1,150°C. (2,102°F.)

Tar burners are employed to heat up the checkers and flues in order to minimize the risk of explosions occurring owing to the possible admixture of air and gas in the flues due to the damper type of valve with which the flues are provided. As previously stated in Section III, these valves were originally designed for the burning of tar in the furnace melting chamber, in which case only air and waste gases traverse the flues, and slight leakages of either owing to the dampers not closing

properly were of little consequence; whereas, in the case of producer gas, leakages are dangerous unless the regenerators and flues are at a sufficiently high temperature to cause the ignition of any gas which may leak under a damper which has not properly closed.

The employment of tar burners in the slag pockets is also of great assistance in maintaining the normal working temperature of the regenerators during the burning out of the flues at the week-end, or while minor repairs to the furnace roof, etc., are being executed, during which the gas is shut off the furnace for several hours; for, by keeping the checkers hot, the temperature of the melting chamber is more rapidly regained after the gas is turned on again.

(e) *Casting House to Stripper Yard*

Directly the ladle has been filled with steel and a covering of slag, it is carried by one of the two 150-ton ladle cranes to the casting platform, alongside which the moulds into which the steel is to be cast have been prepared in readiness. The ladles, of which ten are provided at present, are of 105 to 115 tons capacity and are fitted with one stopper and nozzle only, the latter having a $1\frac{3}{4}$ -in.-diameter hole for all grades of steel. The nozzle is fitted into a pair of well bricks which are placed one above the other and are bricked in the ladle bottom. The nozzle and well bricks are renewed after each cast. The average number of heats obtained from each ladle before requiring relining is 18. The ladles after repairs are dried and heated by means of a tar flame.

The ingot moulds are of cast iron and are made in the Tata Company's own iron foundry. They are used without being annealed (there being no facilities at present for annealing them), and are of the following average composition:

Graphitic carbon.....	3.15 per cent
Combined carbon.....	0.20 "
Manganese.....	1.05 "
Sulphur.....	0.10 "
Phosphorus.....	0.40 "
Silicon.....	1.50 "

Only two sizes of moulds are employed. They are rectangular in shape and are tapered, and are used narrow end up. The interior dimensions of the smaller moulds are approximately $19\frac{1}{2}$ in. by $22\frac{1}{2}$ in. at the top end and 22 in. by 25 in. at the bottom end, and have a capacity of $3\frac{3}{4}$ tons, while the larger moulds are approximately $23\frac{1}{2}$ in. by 28 in. at the top end and 26 in. by 31 in. at the bottom end, with a capacity of $5\frac{3}{4}$ tons. Both classes of moulds are 72 in. in length and they are provided with a pair of lifting lugs at the narrow (top) end for stripping purposes. Three complete sets of large moulds and one complete set of small moulds are kept in operation. The moulds are placed on cast iron bottom plates, or stools, which are supported on ingot cars, each car being designed to hold four moulds and stools. The stools are 6 ft. 0 in. long by 3 ft. 9 in. wide by 8 in. thick, and are cast from blast-furnace metal in open sand. They have the following average analysis:

Graphitic carbon.....	3.45	per cent
Combined carbon.....	0.58	"
Manganese.....	1.20	"
Sulphur.....	0.04	"
Phosphorus.....	0.34	"
Silicon.....	0.80	"

The moulds are usually hot from the previous cast when being prepared, and to make up the joint between the stool and the mould a little slurry made from red clay is poured into the mould and allowed to dry, while moistened red clay is also placed on the stool round the outside of the mould to lessen the possibility of steel breaking out from under the mould during casting. The moulds are coated inside with tar or plumbago before being cast into. The steel is top cast into the moulds direct from the ladle through the $1\frac{3}{4}$ -in.-diameter hole in the nozzle, and the average speed of casting is approximately 5 tons per minute.

The average weight of each ingot cast in the smaller moulds is $71\frac{1}{2}$ cwt., 30 ingots of this weight being cast from one heat. These smaller ingots are mostly made for rolling in the old mills. The average weight of each ingot cast in the larger moulds is 107 cwt., and 20 ingots of this weight are cast from one heat, these larger ingots being made solely for

rolling in the new mills. The average number of ingots obtained from the smaller moulds before being discarded is 72, with a total output of $257\frac{1}{2}$ tons, while the average number obtained from the larger moulds is 60 with a total output of 321 tons. The average life of the stools is 275 ingots, both large and small. The mould consumption is approximately $32\frac{1}{2}$ lb. per ton of steel ingots produced for the smaller size and $36\frac{1}{2}$ lb. per ton for the larger size. The stool consumption is $4\frac{3}{4}$ lb. per ton of steel ingots. It is found that the life of the moulds is considerably increased by casting in them while they are moderately hot from a preceding cast, as the strains caused by the alternate expansion and contraction to which they are subjected are thereby lessened and thus they are much less liable to develop cracks.

During the casting of the ingots three samples are taken for analysis, one while casting the third ingot, one about the middle of the cast, and one while casting the third from the last ingot; that is, samples are taken while casting the third, tenth and seventeenth ingots respectively, for a twenty-ingot cast. A complete analysis is made of the middle sample, while the other two samples are usually analyzed for carbon only. The middle sample is also forwarded to the Indian Government Metallurgical Laboratory at Jamshedpur for the analysis to be checked. The samples are taken in a spoon and poured into tapered moulds, 3-in. square at the top and 2-in. square at the bottom and 6 in. in length, made in two halves and held together by placing moistened clay round their bases while they stand on the casting platform.

For all steels except 'rimming' steel, aluminium in shot form is added a little at a time in the moulds during casting, care being taken to only add sufficient to nearly, but not quite, 'kill' the steel, so that the tops of the ingots slightly rise before the ingot solidifies. This is done to prevent, as much as possible, 'piping', which would otherwise occur if the steel were well 'killed' by the addition of more aluminium, particularly when no feeding heads are employed. The average weight of aluminium added for these almost 'killed' steels is about 2 ounces per ton for rail steel, $3\frac{1}{2}$ ounces per ton for mild (structural), and 4 ounces per ton for tin-bar steel.

'Rimming' or 'effervescing' steel is occasionally made for sheet-bar and tin-bar, and at the present time comparisons are being made of the yield of finished rolled material made from this steel and from the almost 'killed' steel referred to above; but so far the latter has been found to give much the better yield. 'Rimming' steel is, however, a little cheaper to make, as no silicon is added to the furnace or the ladle and much less aluminium is required in the mould; but whereas no piping occurs in the ingots, considerably more segregation takes place.

When making 'rimming' steel there is no difference in the working of the furnace from the method described for ordinary steels, except that care is taken to obtain a highly oxidizing and mobile slag just prior to tapping; and whereas it is not necessary to greatly over-oxidize the steel, it must contain a sufficient amount of CO to produce the 'rimming-in' effect in the moulds. It is essential that silicon be eliminated to a very high degree, as this element in the bath protects the carbon from oxidation and thus diminishes the vigour of the boil, and, therefore, limits the amount of CO formed. On this account no silicon whatever is added, either in the furnace or in the ladle. The amount of aluminium added in the moulds while casting depends on the behaviour of the steel in the first mould during the evolution of the gas. Effervescence may be either too strong or too weak. Too vigorous effervescence is caused by over-oxidizing the steel as the result of there being too great an excess of oxide of iron in the furnace bath when the furnace was tapped. In this case, the steel settles excessively in the moulds as it freezes, sometimes to almost half its former volume. This settling of the steel can be counteracted by suitable aluminium additions, and the addition of the correct amount of this deoxidizer, probably 3 ounces per ton of steel, will cause the steel to 'rim-in' level. Too weak effervescence is caused by there being too little an amount of oxide of iron in the bath before tapping the furnace, or the steel has been tapped at too high a temperature. The result, in this case, is that the steel rises considerably after casting and may flow over the tops of the moulds. If the steel begins to rise without any additions of aluminium, slow teeming is the only means to check it. When the evolution of gas is

right, the steel during effervescence tends to settle about 2 in. or 3 in. in the first mould, and the addition of a little aluminium, usually about one ounce per ton of steel, is required in the other moulds to cause the ingots to 'rim-in' horizontally and have flat tops, which is the desired object.

It frequently occurs that, although the major portion of the steel has rimmed in horizontally, the last steel to solidify in the centre of the ingot has a tendency to rise considerably on account of gas still remaining in the steel being evolved at an increased pressure due to the increased resistance caused by the diminished area of liquid steel left for its evolution at the top of the ingot. In such cases it is the custom to place a flat steel or cast iron plate about 18 in. square and 1 in. thick on the top of the ingot as soon as this tendency to rise is observed, in order to check it.

When the steel is excessively hot in the mould, there is no effervescence and the steel continues to rise after teeming. Such ingots will consequently have spongy tops unless an excessive amount of aluminium is added to thoroughly deoxidize the steel, in which case the ingots will be badly 'piped'. The most satisfactory 'rimming' steel is made when the casting temperature of the steel is such that a bottom skull is left in the ladle after casting.

For loosening skulls, a piece of rail is placed through the nozzle hole in the ladle bottom after the used nozzle has been removed, and in contact with the skull. The rail is then struck by a 5-ton ball swung by one of the crane hoists, and when the skull is sufficiently loosened it is lifted out of the ladle by the crane.

The average loss of steel in the casting house, that is, from the weight of steel poured from the furnace into the ladle to steel ingots despatched to the mills, is approximately $2\frac{1}{2}$ per cent, the average weight of ladle skulls being about 2,400 lb. or 1 per cent of the weight of steel ingots, while other losses due to the occasional casting of butt ends of ingots which are too short to roll, running stoppers, spillings, etc., average $1\frac{1}{2}$ per cent. The average yield, therefore, from blast-furnace metal (including subsequent additions during its conversion) to steel ingots works out at a little over $85\frac{1}{2}$ per cent.

As soon as a heat has been cast, the ingots on the cars are shunted by a steam locomotive to the stripper yard.

(f) *Stripper Yard to Soaking Pits*

Stripping is usually commenced 20 minutes after the last ingot was cast in the case of soft and mild steels, and 50 minutes after casting the last ingot in the case of rail steel.

As previously stated, the ingots are cast narrow end up. The moulds are therefore lifted off the ingots by the slings of the 150-ton stripper crane, which fit over the pair of lugs provided at the top end of each mould for stripping purposes. As the mould is lifted the ingot is pressed against a vertical ram fitted on the crane.

As the hot ingots are stripped, the moulds are placed on bottom plates on other ingot cars used for the previous cast, and as soon as all the ingots have been stripped they are shunted by a steam locomotive on 36.-in.-gauge tracks to the blooming mill soaking pits building, where the ingots are lifted off the bottom plates by one of two 7½-ton 76-ft.-span Alliance soaking pit charging cranes and placed in one of a series of eight 4-hole soaking pit furnaces which are served by three Morgan 10-ft.-diameter gas machines. Soft and mild steel ingots are usually delivered to the soaking pits within 1½ hours of tapping the furnace, and rail steel ingots within 2 hours.

On the return journey, the ingot cars with the bottom plates are shunted under an 81-ft.-span crane fitted with two 5-ton trolleys in the middle bay of the structural finishing department (referred to on page 292), which is situated at the north end of the rail and structural mill building, and the bottom plates are cleaned and straightened-up on the ingot cars, which are then returned to the stripper yard. As the next cast of ingots are stripped, the moulds are placed one by one on the bottom plates from the previous cast, and the ingot moulds fixed on the bottom plates are then shunted back to the casting house.

SECTION VI. CONCLUSION

The use of steel scrap is absolutely essential for the economical working of the straight open-hearth process, whereas one of the underlying causes of the growth of the Duplex process, especially in America, is its independence of a steel scrap supply; and if the cost of scrap exceeds a certain amount, the adoption of the latter process of steel making becomes almost a necessity.

The cost of plant per ton of ingots produced, embracing additional blast furnace capacity, Bessemer converters, and open-hearth tilting furnaces, is fully as great as the cost of stationary open-hearth furnaces per ton of ingots, but the Duplex plant possesses greater flexibility, and, obviously, the most profitable location of such a plant is where the production of molten pig iron in the blast furnaces is on a low-cost basis compared with the normal price of steel scrap.

The Duplex process is also particularly suitable for the conversion of phosphoric iron into steel in districts where low-silicon iron cannot be made without high sulphur, and, furthermore, iron which is high in silicon can be used with more rapid conversion.

Although the total cost per ton of steel made by the Duplex process, working with 100 per cent hot metal (with which the most rapid work is accomplished), is a little lower than the straight open-hearth process using 50 per cent hot metal and 50 per cent steel scrap, the chief advantage of the former process is the very large outputs which can be obtained, for one 200-ton or 250-ton furnace in combination with two 25-ton Bessemer converters at the Tata works can produce 24,000 tons of tin-bar and structural steel per month, which is more than the total output of the four 55-ton and three 75-ton stationary open-hearth furnaces; and as much as $1,065\frac{3}{4}$ tons of steel ingots have been made in 24 hours from one of the Duplex open-hearth furnaces at these works. Table XXII shows the record for 'B' furnace making tin-bar steel during 24 hours from 6 a.m. September 8th to 6 a.m. September 9th, 1926:

Table XXII.—Record output of 'B' Duplex open-hearth tilting furnace during 24 hours

Cast No.	Time furnace commenced to charge		Time furnace tapped		Length of time heat in furnace		Weight of ingots cast	
	hr.	min.	hr.	min.	hr.	min.	tons	cwt.
6024	4	35	7	10	2	35	107	15
6025	7	35	10	10	2	35	106	15
6026	10	30	12	35	2	05	110	0
6027	12	55	15	00	2	05	106	15
6028	15	10	18	05	2	55	112	0
6029	18	20	20	30	2	10	108	10
6030	20	45	22	20	1	35	104	5
6031	22	55	0	35	1	40	105	0
6032	1	20	3	00	1	40	99	15
6033	3	40	5	50	2	10	105	0
					Total.....		1,065	15

The Duplex process shortens open-hearth purification by at least three-quarters of its usual duration, and yields quite as good a product; for, with ordinary care, the steel made by the Duplex method is of excellent quality. One of the most important points, so far as the open-hearth stage of the process is concerned, is to make certain that the phosphorus is eliminated before the carbon, and, so long as there is carbon present which has to be oxidized in the final stages, the possibilities of tapping steel that is 'wild' are considerably diminished; and provided that oxygen is kept out of the finished product, Duplex steel is equal to the best steel manufactured by any other process.

The whole of the open-hearth stage of the Duplex process is usually carried out with great rapidity, and it is because of this, and the necessity for frequent taps, that tilting furnaces are now always employed; for if there were any delays in pouring a heat owing to taphole troubles, much larger tonnage losses would follow than with stationary open-hearth furnaces. As this could not be tolerated, the extra capital expense incurred in the erection of large tilting furnaces is therefore justified.

The rated capacity of the Duplex plant of the Tata Iron and Steel Company with present equipment is 30,000 tons per month, or 360,000 tons per annum. This rated monthly output was reached for the first time in November, 1926, when 30,385 tons of steel ingots were produced, improvements in practice having yielded an increase in production of nearly 5,000 tons or 20 per cent above the previous best month; while in December, 1926, the output was further improved upon. As previously stated, considerable delays in charging the furnaces are bound to occur with the present equipment. Up to the end of 1926, only one 100-ton ladle crane was provided to serve the furnaces at the charging side. A second crane, however, of similar capacity was erected in January, 1927, and this has eliminated some of the delays previously experienced in charging blown metal into the furnaces. Additional transfer and casting ladles are also to be provided. The main cause of the delays which occur is the inability with present electrical equipment to blow two converters simultaneously, so that, whenever both open-hearth furnaces tap about the same time, one furnace is compelled to wait until the other is wholly or partly charged. Other delays which further restrict the output of the furnaces are caused by the temporary suspension of blowing owing to the frequent necessity of blanking-off one or more defective tuyeres on one converter bottom while a newly lined bottom is being placed on the other vessel. Furthermore, whenever one converter is out of commission for a few days for relining, or owing to mechanical or electrical breakdowns, a delay in blowing of at least one hour is experienced each time a newly lined bottom is required on the converter in use. Therefore, to obviate these delays, it is necessary to have a third converter as a spare vessel.

When one open-hearth furnace is down for repairs, the other furnace makes mild and low-carbon steels only, which are the quickest to produce, so that a production rate of 24,000 tons per month is easily maintained, as, with only one furnace working, delays in charging do not occur providing both converters are in operation. As soon as the repaired furnace is operating, however, one of the furnaces is turned

on to rail steel, which takes about twice as long to produce as mild or low-carbon steels, and this, together with the charging delays already referred to, considerably reduces the production rate per furnace.

The output of steel ingots per furnace is, therefore, considerably below that of similar Duplex plants in America, but this is mostly attributable to the present inadequate equipment and also to the fact that, in America, rail steel is seldom made by the Duplex process. In the latter country, however, rail steel does not take any longer to make than mild or low-carbon steels, as all heats are worked similarly and the necessary carbon obtained by recarburizing with molten spiegel in the casting ladle while the metal is being poured from the furnace. Although the method of making rail steel at the Tata works is somewhat longer than the American method, it has been admitted by American experts who have had experience in American Duplex practice, that the Tata method produces a much better quality of rail steel, which will readily pass British standard specifications.

By installing a third converter as a spare unit, together with the necessary electrical equipment so that two converters can be blown simultaneously, and providing more transfer and casting ladles, the present average monthly output could be considerably increased, and there would be no reason why, in the cold season, the production of steel per furnace should not be equal to that of the most efficient Duplex plant in America.

Under existing conditions, however, the output of the two Duplex open-hearth furnaces at the Tata works is restricted to a maximum of 15 heats, or approximately 1,600 tons of steel ingots per 24 hours, when one furnace is producing rail steel and the other mild or soft steels.

The nearest approach to this output to-date is 1,568 tons 18½ cwt. of rail, tin-bar, and structural steel ingots obtained during 24 hours from 6 a.m. January 20th to 6 a.m. January 21st, 1927, particulars of which are given in Table XXIII:

Table XXIII.—Record output of 'A' and 'B' Duplex open-hearth tilting furnaces during 24 hours

Cast No.	Furnace	Grade of steel	Time furnace commenced to charge	Time furnace tapped	Length of time in furnace	Weight of ingots cast	
			hr. min.	hr. min.	hr. min.	tons	cwt.
7133	B	Tin-bar	6 20	9 05	2 45	109	1
7134	A	Rail	6 15	10 15	4 00	109	17½
7135	B	Structural	9 30	11 25	1 55	117	9½
7136	A	Structural	10 50	13 00	2 10	104	13½
7137	B	Tin-bar	11 50	13 45	1 55	112	17½
7138	B	Tin-bar	14 25	16 25	2 00	113	15
7139	A	Rail	13 25	18 15	4 50	112	13
7140	B	Tin-bar	16 50	19 20	2 30	115	18
7141	A	Tin-bar	19 00	21 30	2 30	112	9
7142	B	Rail	20 25	23 25	3 00	111	8½
7143	A	Rail	21 45	2 00	4 15	112	17
7144	B	Tin-bar	24 00	2 25	2 25	110	10
7145	A	Tin-bar	2 30	4 55	2 25	115	7½
7146	B	Tin-bar	4 25	5 45	1 20	110	1½
Total...						1,568	18½

In Table XXIV is shown the production of steel ingots obtained from the Duplex plant of the Tata Iron & Steel Company during the year 1926.

Table XXIV.—Production of steel ingots from "A" and "B" Duplex open-hearth tilting furnaces during 1926

Month 1926	Number of furnaces working	Rail steel	Mild and low-carbon steels		Total weight of ingots produced	
		Weight of ingots	Weight of ingots			
		tons cwt	tons	cwt	tons	cwt
January	1.94	1,855 19	23,469	15	25,325	14
February	1.64*	1,574 9	18,399	17	19,974	6
March	1.74†	5,252 3	16,443	8	21,695	11
April	2.00	5,607 11	17,789	18	23,397	9
May	2.00	3,262 15	18,980	9	22,243	4
June	1.80‡	3,073 13	17,669	4	20,742	17
July	1.87§	3,435 16	20,816	3	24,251	19
August	2.00	6,772 5	18,688	9	25,460	14
September . . .	1.67*	3,406 14	18,817	1¼	22,223	15¼
October	1.68†	3,386 1½	20,122	17½	23,508	19
November . . .	1.97	8,127 7	22,258	6	30,385	13
December . . .	1.90	9,006 17½	22,331	6	31,338	3½
Total . . . .	....	54,761 11	235,786	13¾	290,548	4¾

*'A' furnace off for general repairs.

†'B' furnace off for general repairs.

‡'A' furnace off for roof repair.

§'B' furnace off for roof repair.

Until the 30th October, 1926, the furnaces operated alternately $6\frac{1}{8}$ and $6\frac{3}{8}$ days per week, but after this date the time of operating was extended to $6\frac{1}{4}$ and $6\frac{1}{2}$ days, the furnace which requires the flues burning out tapping the last heat about noon and the other furnace about 6 p.m. each Saturday. The Duplex plant was kept in operation every week-day during the whole 52 weeks of the year, with the exception of Christmas day.

The climate has a great influence on the output of the plant, for during the very hot season the temperature becomes so high that it saps the energy and severely taxes the powers of endurance of the furnace men. From the end of February to the middle of June, the shade temperature rises from about 95°F. until 115°F. or even higher is registered during the hottest period of the day. The latter maximum temperature is reached daily for about three weeks before the middle of June, when the monsoon or rainy season commences and continues until about the middle of September. During the monsoon season, frequent stoppages occur in the operation of the plant, chiefly on account of electrical breakdowns caused by the torrential rains. Although the maximum shade temperature gradually falls to about 95 F. during the latter season, the atmosphere is very humid. After the heavy rains, the climate from about the middle of September to the end of February becomes very pleasant, the shade temperature during the hottest part of the day gradually falling until a maximum of about 80 F. is registered about the middle of December, while the nights are very cool, there being a large diurnal range of temperature during this period. After the middle of December, the temperature gradually increases and the diurnal range steadily decreases until the latter becomes very small during the very hot season. It is, therefore, during the period from September to February that the largest monthly outputs are expected.

The products of the Tata Iron & Steel Company consist chiefly of rails, fish plates and pressed steel trough sleepers; beams, channels, angles and tees; various sizes of bars, tin-plate bars, which are supplied to the Tinplate Company of India

(a subsidiary company) to be rolled into tin-plate; sheets (black and galvanized) and plates; and also blooms and billets for sale.

The average mill yields of good rolled material from steel ingots compare very favourably with average English and American practice, and are as follows:

Rails (various weights per yard) and structural sections, 80 per cent; tin-bar, 86.75 per cent; sheet-bar, 87.5 per cent; blooms, 89.75 per cent; billets, 88.5 per cent; and plate slabs, 88.0 per cent.

The total number of employees engaged in the Jamshedpur works of the Tata Iron & Steel Company is about 29,000. Of this number, 160 are imported British and American covenanted hands specially engaged in supervisory capacities, or in the highly skilled trades, such as Bessemer steel blowing, open-hearth furnace melting, etc. The number of covenanted hands has been gradually reduced year by year and Indian hands substituted as the latter have become sufficiently experienced, and in the Duplex plant, where about 1,750 employees are engaged, every department is operated solely by native workmen and foremen, with the exception of the Bessemer department and the open-hearth melting platform. In the Bessemer department, covenanted American foremen and steel blowers are employed with Indian labour for the less skilled jobs, and on the open-hearth platform covenanted British and American foremen and first hands are engaged, while the second hands are a mixture of covenanted hands, locally engaged white men, and technically trained natives, there being a technical school in Jamshedpur where students are taught metallurgy and are subsequently engaged by the Tata Company upon completion of the metallurgical course. All the furnace third hands and the less skilled hands are natives.

Although the average wage of Indian workmen is very low in comparison with the wages of British and American workmen engaged in similar work, and averages approximately one rupee (1s. 6d.) per day, Indian labour is not particularly cheap. The real test is not the rate of wages so much as the amount of work done in a given time, and frequently it is essential to employ at least six natives to accomplish as much work as one competent British or American workman will do

in the same time. It is also necessary to employ a much larger labour force than is actually required, as the number of absentees owing to illness, religious festivals, compulsory holidays, and various other reasons, varies remarkably, and whereas on one day more than 90 per cent of the workmen may be present, the next day less than 75 per cent may be on hand.

However, taking into consideration the many difficulties to be faced in the manufacture of steel in a tropical country, the Tata Iron & Steel Company is to be congratulated on the very rapid progress achieved from year to year; for although the firm only commenced operations three years prior to the beginning of the late European War, it is now capable of producing more iron and steel per annum than any other single firm in the British Empire.

ACKNOWLEDGMENT

In conclusion, the author desires to express his thanks to the Directors of the Tata Iron and Steel Company for their kind permission to publish the records and information contained in the foregoing pages; also to Messrs. C. A. Alexander and J. L. Keenan, respectively General Manager and General Superintendent, for their keen interest in the paper; and to the departmental superintendents who so willingly assisted by supplying various items of information required by the author.

MAGNESIA REFRACTORIES FOR STEEL FURNACES

BY G. M. CARRIE (*Member, C. Inst. M. & M.*)*
AND C. F. PASCOE**

(Montreal, Que., Meeting, August 22nd, 1927)

INTRODUCTION

The subject of basic refractories is daily becoming of increased importance in metallurgical processes, and there is a constantly growing necessity for the development of better materials. This fact, together with the realization that Canada possesses one of the best sources of such refractories in the British Empire, if not in the world, made it appear advisable that the subject be presented to the Empire Mining and Metallurgical Congress at the 1927 meeting. Having been in close touch with developments in the Canadian product during the past five years, G. M. Carrie was requested to prepare such a paper.

The Canadian producers of magnesia refractories have succeeded in developing the product to a place where it has almost entirely displaced imported materials from the Canadian market. These developments were made possible by a close study of the methods of preparation of the material, and by an exceedingly careful control of the manufacturing process so as to obtain a thorough blending of the different constituents with the resultant uniformity of composition. This point is very important to the metallurgist, as un-uniform materials are a potent cause of difficulties in most manufacturing processes and the constant trend is towards their elimination. The temperature at which the Canadian material is burned ensures high specific gravity and thorough shrinkage. The grain size of the product is so controlled that the voids are only just sufficient to allow of proper bonding, thus making possible a dense, hard bottom affording high resistance to erosion and shock. Careful proportioning of the constituent elements absolutely prevents disintegration.

*General Manager, Scottish Canadian Magnesite Co., Ltd.

**Chief Metallurgist, Canadian Car and Foundry Co., Ltd.

The subject is very large, and no attempt has been made to cover it in a detailed manner; but rather to outline the occurrence of the raw materials and to indicate the conditions under which the finished product operates. Reference has been made to many previous investigations, but there seems to be a lamentable lack of agreement between many of the results obtained, due, possibly, to varying methods and conditions of treatment of the work. The *Transactions* of the American Institute of Mining and Metallurgical Engineers and the publications of the American Ceramic Society have been frequently quoted in this paper, and have been of great assistance. The findings of some of the many investigators have been noted, and an effort has been made to give the proper credit to the original investigator in each case. No detailed bibliography is included, as the various excellent bibliographies compiled by the American Ceramic Society cover the subject in an exceedingly painstaking manner.

HISTORICAL

The open-hearth process of making steel is a comparatively recent development. Siemens started to work out a regenerative system for the development of higher working temperatures in the manufacture of zinc, glass, and steel, and found that he had no great difficulty in obtaining the temperature, but that the chief difficulty was in controlling it. About 1868, one of the first open hearth furnaces was installed at Crewe, in England, and there was a furnace built about the same time in Trenton, New Jersey. The use of magnesite as a refractory in the manufacture of steel appears to have been first considered about 1860 (22)*, and from that time until 1879, when Siemens stated that magnesia was a splendid furnace lining, but very expensive, there had been a certain amount of work done on the subject.

The discovery by Thomas and Gilchrist of a new method of steel making, in which it was possible to eliminate phosphorus by the use of a furnace lined with basic materials, and the

*Numbers enclosed in brackets refer to bibliography at end of paper.

subsequent development of this process, made it very evident that a basic refractory must be developed, if full advantage were to be taken of the new discovery.

At first the basic open-hearth, and the basic bessemer, furnaces were lined with dolomite, with fairly good results. Grecian magnesite was then employed, but it was difficult to sinter owing to its purity. After considerable work had been done with dolomite and Grecian magnesite, there was discovered in Styria a large deposit of crystalline magnesite, which contained quite a high percentage of iron in the form of the carbonate, and had the property of sintering into a hard, dense mass when heated. It was also discovered that this material could be made into brick, which was hard, dense, and resistant to the action of slag.

The first introduction of magnesite into the United States appears to have been by the Otis Steel Company of Cleveland, about 1885.

On account of its early association with the manufacture of steel, and owing to the fact that it contains, naturally, a sufficient percentage of iron to enable it to be easily worked, the Austrian magnesite, up to 1914, maintained an almost unchallenged supremacy in the field of basic refractories. When the war broke out, however, in August, 1914, and Austrian supplies were cut off, it became necessary to find other sources of supply, and, as a result, deposits were developed in Canada (Grenville), and the United States (Washington and California).

The Grecian deposits were drawn on to a very large extent by Great Britain and France. It was necessary, in most instances, to add sufficient iron to the crude rock to allow of its being properly sintered and bonded. The steel manufacturers also turned to dolomite as a substitute for magnesite, with more or less success, depending on circumstances and conditions.

NOMENCLATURE

There is a great deal of laxity in the terms used for the different magnesia compounds. Most of the definitions given below are those tabulated by McDowell & Howe (6), and

represent a commendable effort on their part to clear up a certain amount of confusion as to the meaning of the different terms used.

Magnesite.—The mineral MgCO_3 , — the crude material of the magnesite industry. A term applied to various products manufactured from the mineral MgCO_3 , such as 'dead-burned magnesite', 'plastic' magnesite, magnesite brick, and so forth.

Plastic Magnesite, or Caustic Magnesia.—The product which results from calcining crude magnesite at a comparatively low temperature, and which contains from 2 to 5 per cent carbon dioxide. This material is very active, slakes in contact with water, and combines with magnesium chloride to form a hard, strong, material known as *oxychloride*, or *Sorel cement*.

Dead-burned Magnesite, Sintered Magnesite, or Dead-burned Magnesia.—A sintered product obtained by calcining magnesite at a very high temperature, usually about $1,700^\circ\text{C}$. It usually contains less than 0.5 per cent carbon dioxide, and 4 to 8 per cent iron oxide, the latter either naturally or by addition of iron-ore during treatment. The product is exceedingly refractory and is chemically inert. It does not slake in air or water, but tends to disintegrate in contact with steam.

Calcined Magnesite.—Magnesite which has been calcined at any temperature. This term includes both caustic and dead-burned, but usually indicates a product intermediate between these materials, and one in which the carbon dioxide content is below 2 per cent.

Electrically Sintered Magnesia.—Magnesite calcined in the electric furnace to ensure complete shrinkage; usually of a high degree of purity.

Magnesia or Magnesite Brick.—Brick consisting essentially of magnesium oxide, and generally containing from 4 to 8 per cent iron oxide. It has been suggested that brick with this amount of iron be called 'magnesite brick', and those nearly free from this impurity be called 'magnesia brick'; however, the latter term is more frequently applied to both.

Magnesia.—(1) The pure oxide of magnesia; (2) A term applied synonymously with 'magnesite' to brick, dead-burned material, and so forth; (3) Certain magnesite products low in

impurities and high in magnesium oxide, such as magnesia crucibles, electrically shrunk or fused magnesia, etc.; (4) Precipitated or basic carbonate of magnesia.

Basic Carbonate of Magnesia.—A light powdery material prepared either by boiling a solution of acid magnesium carbonate or by double decomposition of a soluble magnesium salt, and a soluble carbonate. Its composition is indefinite, and, with its properties, depends on the mode of preparation. It is generally given as $3\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$, the same as that of hydromagnesite.

Periclase.—The crystalline form which magnesium oxide takes when subjected to prolonged high temperature.

Dolomite.—Mineralogically, the double carbonate of calcium and magnesium, $\text{CaCO}_3 \cdot \text{MgCO}_3$, but has a very wide application in practice. Usually taken to include also dolomite rock ranging in composition from a limestone with more than 10 per cent magnesium carbonate to a magnesite containing more than 10 per cent calcium carbonate (See also under 'Refractories available', p. 456).

Calcined Dolomite.—The product obtained by heating crude dolomite so as to drive off all but about 2 or 3 per cent of its carbon dioxide.

Double Burned Dolomite.—The product obtained by calcining dolomite lightly in one kiln, and then subjecting it to high temperature in a second kiln.

Synthetic or Treated Dolomite.—Dolomite which has been burned and which has been treated to prevent hydration, or which has, before burning, been mixed with various substances to prevent hydration.

USES OF MAGNESITE

The materials which are made from magnesite, or have magnesite as their base, are in very widespread use. Only a brief outline of the different uses will be attempted here.

1. *Refractories.*—Both dolomite and magnesite have a base of magnesium oxide and are extensively used for refractory purposes in the treatment of steel, copper, nickel, lead, etc. They are used in open-hearth furnaces, bessemer converters, reheating furnaces, ladles and other vessels used in metallurgy.

Their usefulness is due primarily to the high fusion point and chemical inertia of the oxide of magnesium. They are usually employed in the dead-burned form, though sometimes the calcined material is used. Made up into brick, they find extensive use in the construction of metallurgical furnaces.

2. *Oxychloride Cement*.—A mixture of finely-ground caustic calcined magnesite and magnesium chloride has been used extensively in recent years in the manufacture of stucco, flooring, tile, and other structural material. The use of magnesite for this purpose is based on the fact that magnesium oxide, when mixed with a solution of magnesium chloride of a certain concentration, sets very hard and is very strong mechanically. Its high strength allows of the admixture of fillers, such as sawdust, cork, and other materials, to make a resilient flooring. It can be coloured, takes a good polish, is water-proof and fire-proof, and does not dust. For this use it has been customary to employ the purer grades of magnesite, such as Indian, Grecian, and Californian, but recent discoveries have shown that it is possible, with proper treatment, to use any of the better classes of magnesite.

3. *Carbon Dioxide*.—Considerable quantities of magnesite were formerly used for manufacture of carbon dioxide, but limestone or coke is now generally used for this purpose; although magnesite is still employed to a certain extent in South Africa. Carbon dioxide is manufactured from the crude magnesite by calcination at a low temperature and the recovery, purification, and compression of the carbon-dioxide gas evolved. The residual caustic magnesia from this process can be recovered and used by the employment of proper methods.

4. *Pulp and Paper Industry*.—Magnesite and dolomite are used in considerable quantities in the manufacture of wood pulp by the sulphite process, generally in the 'milk of lime' process. The preparation involves boiling the wood with a chemical reagent which will serve to disintegrate it. For this purpose, sulphurous acid is used, and calcium or magnesium bisulphite formed. The magnesium bisulphite seems to be preferred on account of the greater solubility of the magnesium compounds, giving a softer pulp.

5. *Magnesium Metal*.—Prior to the war, the world's supply of magnesium was largely produced in Germany, where it is manufactured from magnesium salts, obtained from deposits in that country, by the electrolysis of the fused double chloride of magnesium and potassium. During the war the metal was produced in Canada by the Shawinigan Electro-Metals Company at Shawinigan, Quebec, crude ore from the Canadian deposits in Quebec being used as the source. Recently there have been new developments in processes for the production of the metal, which show possibilities of greatly decreased cost. Metallic magnesium alloyed with aluminium gives a material which is likely, owing to its great strength and lightness, to be of growing importance in manufacturing processes. Magnesium is also used for scavenging purposes and for illumination in photography, fireworks, and military purposes.

6. *Cold Water Paint*.—Because of its refractory qualities, a mixture of caustic calcined magnesite and magnesium chloride is coming into use as a paint in fire-proofing.

7. *Magnesium Sulphate*.—A certain amount of magnesium sulphate is manufactured from magnesite by chemical treatment, but the larger percentage is produced as a by-product in certain manufacturing processes, or is obtained from so-called 'mineral lakes'. By far the greatest proportion is imported from Germany. Magnesium sulphate is used chiefly for medicinal purposes, in tanning leather, in cotton manufacture, and in chemical laboratories.

8. *Magnesium Chloride*.—Magnesite can be used for the manufacture of magnesium chloride by chemical process, but this product is usually obtained as a by-product from the bitters of salt refineries. Magnesium chloride is used in the manufacture of oxychloride cement.

9. *Basic Magnesium Carbonate*.—Magnesite and dolomite are used as the raw materials in the manufacture of basic magnesium carbonate. This product and the oxide are used extensively, mixed with asbestos, as a heat insulator. It is also used for medicinal and toilet purposes.

10. *Miscellaneous*.—Magnesite and its derivatives are used in small quantities for many other purposes, as, for instance, the *carbonate*, to prevent scale in boilers, and in toothpaste; the *oxide*, in the rubber industry; and the *hydrate*, for medicinal purposes; etc.

PROPERTIES OF MAGNESIA

General:

In recent years, there has been quite a large amount of research done by different investigators on the various properties of magnesia. This subject is very large and it is not intended to go into it in a detailed way in this paper, but rather to give some of the chief references on the subject.

Magnesite, when pure, contains, theoretically, 47.6 per cent magnesium oxide and 52.4 per cent carbon dioxide; but impurities may range from 2 or 3 per cent to a much higher figure. It has a specific gravity of 2.90 to 3.08. It occurs in two distinct types, crystalline and cryptocrystalline. The former variety, in general, occurs in Austria, Hungary, the United States (Washington), and Canada; the latter in Greece, India, and the United States (California).

Goodwin and Mailey (25) stated that fused magnesia, prepared in the electric furnace, is light in colour, has a glazed surface, and a hardness of 5 to 6. Mellor (27) has come to the conclusion that there are two forms of magnesia, and that, when magnesite is being calcined, there is first formed a very finely grained amorphous magnesia, with a specific gravity of about 3.20, which he has named '*alpha magnesia*'. As the temperature rises this is gradually transformed into a second material with a specific gravity of about 3.67, which he has termed '*beta magnesia*' (periclase).

Kanolt (26) gives the melting point of magnesium oxide as 2,800°C., and also CaO—2,572°C., Al_2O_3 —2,050°C., and Cr_2O_3 —1,990°C. McDowell & Howe (6) state that the commercial dead-burned magnesite, containing 12 per cent impurities, does not melt at 2,000°C. Rankin and Merwin (92) give the melting points of MgO and CaO as 2,800°C. and

2,570°C., respectively. Goodwin and Mailey (25) estimate the melting point of fused MgO as 1,920°C. Ruff and Goecke (93) give the following:

MgO — 2,009°C. begins to vaporize.
 CaO — 1,990°C. “ “ “
 Al₂O₃ — 2,020°C. melts.

Sosman (94) gives the following as the melting points of the pure oxides:

SiO₂ — 1,470°C. to 1,625°C.
 Al₂O₃ — 2,050°C.
 MgO — 2,800°C.
 CaO — 2,570°C.

Mott (95) gives the boiling points of the pure oxides as:

Magnesia — 3,600°C.
 Lime — 3,400°C.
 Alumina — 3,800°C.

Washburn (28) gives the latent heat of fusion of magnesium oxide as 700 calories per gram, and of calcium oxide as 490 cal. per gram. Green (96) gives the specific heat of magnesite brick as follows:—

Degrees centigrade.....	100	200	400	600	800	1,000	1,100
Specific heat.....	.239	.250	.271	.293	.313	.334	.340

Analysis of material used:

MgO — 87.88 per cent
 CaO — 4.68 “
 SiO₂ — 2.34 “
 R₂O₃ — 2.56 “

Fitzgerald & Bennie (29) give the specific gravity of fused magnesia containing about 6 per cent impurities as 3.57. Goodwin and Mailey (25) give the specific gravity of fused MgO as 3.493 at 20°C.; Moissan's experiments give a range from 3.577 to 3.654.

R. D. Pike (67) states that amorphous magnesite mixed with 5 to 6 per cent iron oxide and heated to 1,550°C. is transformed into crystalline periclase, which is dense, hard, and sintered; and that microscopic examination demonstrates that iron oxide added to the rock under proper conditions is equivalent in action to the iron occurring naturally in the rock.

McDowell and Howe (6) stated that the addition of iron oxide to crude magnesite, which is too low in iron oxide content, will give a satisfactory sintered product. It is stated (97) that the crystalline or amorphous nature of the magnesite has no effect on the quality of the product resulting from burning, as it all becomes amorphous on the liberation of the carbon dioxide.

Gosrow (24) indicates that pure magnesite, if heated in an electric furnace above $1,700^{\circ}\text{C}.$, will result in a hard, dense mass with a specific gravity of 3.65, which shows no additional shrinkage on further heating.

Youngman (68) has investigated the action of magnesite in contact with steam, by placing magnesite bricks in a cylinder under a steam pressure of 100 lb. He notes that even the most thoroughly burned brick will hydrate, disintegrating to a fine powder, and that the content of lime or other impurities has no influence on the result. *Care should be therefore taken not to lay magnesite brick in contact with other materials which have been mixed with water, and also to ensure their being kept dry in storage, and not allowed to become wet at any time.* Some of the fine powder resulting from this disintegration of magnesite brick was taken from the lower section of the hearth of a basic open-hearth furnace, and gave the following screen analysis, etc.: (33)

Screen mesh	% on screen	% cumulative
+10.....	6.50	6.50
+20 to +10.....	4.00	10.50
+40 to +20.....	11.50	22.00
+80 to +40.....	11.00	33.00
+100 to +80.....	1.00	34.00
-100.....	66.00	100.00

The chemical analysis of the fine powder was:

SiO_2	6.50 per cent
Al_2O_3	1.35 "
Fe_2O_3	5.33 "
CaO	3.32 "
MgO	76.59 "
Loss on ignition.....	7.02 "

Donald (88) states that microscopic examination of dead-burned magnesite in brick-form shows that the crystal growth is quicker and more regular when the impurities are evenly distributed, and that the impurity magma should interpenetrate the finest interstices.

Slade (98) states that MgO is reduced by carbon at a temperature of $1,700^{\circ}\text{C}$. or above. Kowalke and Grenfell (99) find that the reaction between magnesia and carbon commences slowly at $1,950^{\circ}\text{C}$. and becomes violent at $2,030^{\circ}\text{C}$.

Hedvall (100) has studied the reactivity of silica with the oxides of calcium and magnesium by means of heating and cooling curves. Lime and silica (pptd.) react at $1,011^{\circ}\text{C}$. The reaction ceases and a more vigorous one begins shortly above $1,400^{\circ}\text{C}$. CaCO_3 is acted on by pptd. silica at or below 900°C . No arrest was found on the heating curve of silica and magnesia.

Bischof (101) states that magnesite brick do not react with fire-brick below $1,600^{\circ}\text{C}$., but above that temperature a fluid grey slag forms.

Hydration:

Campbell (30) has studied in great detail the influence of the temperature of burning on the rate of hydration of magnesium oxide, using material of the following analysis:

MgO	— 90.78 per cent	
CaO	— 3.96	“
SiO_2	— 2.53	“
R_2O_3	— 2.70	“ (Calc'd. on a zero ignition loss)

He found that the material required 44.59 per cent of its own weight of water for complete hydration. A summary of his results follows:

Temperature
of burning
(deg. C.)

600	}	... Completely hydrated in 3 days.					
700							
800							
900	}	... Completely hydrated in 3 months.					
1,000							
1,100							
1,200		... 91.8% in 12 mos.; 100% in 24 mos.					
1,300		... 64.0	“ 12	“ 76.2	“ 24	“ 85.5%	in 36 mos.
1,400		... 62.0	“ 12	“ 75.3	“ 24	“ 81.0	“ 36 “
1,450		... 51.2	“ 12	“ 61.7	“ 24	“ 70.3	“ 36 “

He finds that between 1,000°C. and 1,100°C. there is a marked decrease in the rate of hydration.

Gosrow (31), in examining the hydration of small lumps of caustic magnesite exposed to moist air, obtained the following results:

Time of exposure, hours	Increase in weight, per cent
30	2.50
44	3.25
76	3.70
100	4.60
125	5.25
150	5.60
172	6.00

In his experiments, he used material of the following analysis (6):

MgO	—	75.70 per cent
CaO	—	0.10 “
R ₂ O ₃	—	1.90 “
SiO ₂	—	0.85 “
CO ₂	—	2.20 “

McDowell and Howe (6) have studied the action of different materials when moistened daily and exposed to the atmosphere at room temperature, with the following results:

Material	F	A	B	C	B	E
Silica.....	2.40	7.40	4.57	11.52	9.94	6.93
Alumina.....	1.00	2.34	2.08	3.93	1.88	4.03
Iron oxide.....	1.22	4.83	7.89	4.43	4.58	1.73
Lime.....	56.51	3.13	18.96	48.15	49.19	51.64
Magnesia.....	38.69	81.93	66.66	32.26	35.18	35.75
Total.....	99.92	99.63	100.16	100.29	100.77	100.08
Loss on ignition after						
0 days.....	14.04	1.02	.20	.08	.95	3.93
5 “ 	25.52	0.48	.69	1.20	5.67	18.45
10 “ 	26.30	0.96	1.52	1.62	8.35	20.00
15 “ 	33.00	1.24	1.94	2.39	10.10	23.30
20 “ 	29.70	1.36	1.92	3.01	10.92	23.66
25 “ 	25.99	2.09	2.65	6.30	12.00	24.33
30 “ 	30.81	2.54	3.25	4.63	14.99	24.67

They conclude from the above, that, in the case of both magnesite and dolomite, the rate of hydration increases with the lime content and that the presence of impurities reduces, but does not overcome, the inherent tendency of the lime to slake. Recent work carried out by the Canadian producers has tended to indicate that the proportions of the various subordinate constituents, and the temperature of burning of the original material, have an important influence on the tendency of the material to slake. It might be noted in passing that there is a possibility that the sample 'B' used by McDowell and Howe may not have been representative of the material being studied. It has been found, for instance, that a material somewhat similar to sample 'B', and having the following composition:

Silica.....	4.30
Alumina and Iron oxide }	5.98
Lime.....	17.00
Magnesia.....	72.30

after treatment similar to that by McDowell and Howe, had a loss on ignition at 950°C. of only 0.76 per cent at the end of 9 months (33); also, material similar to sample 'B', but having a lime content of about 20 per cent when in the dead-burned state, has withstood the action of boiling water for over 3 months without disintegration. These results would seem to indicate that the temperature of burning, and the care exercised in proportioning the impurities, have a marked influence on the rate of hydration, and that, if properly handled, the lime (if not present in too large amount) can be rendered stable.

Schurecht concludes that, in most cases, an increase in temperature of burning, and increase of impurities, decrease the tendency to gain in weight. He states that a material containing 11 per cent CaO in the raw state, when dead-burned with 10 per cent iron-ore, increased only 0.85 per cent in weight in 160 days under test.

Parravano and Mazzetti (91) conclude that certain impurities present exert a marked influence on the velocity of hydration of the oxide, and facilitate conversion into the dense form. This change they note as being slow at first, and gradually increasing in rapidity as the temperature is raised.

Resistance to Slag Action:

It has been shown (86) that the action of slag on refractories is a combination of penetration and solution, and that the slag-penetration test is of little practical value, due to the fact that the result may be obscured by the varying resistance of different refractories to the solvent action of slag. The action of slag upon different refractories has been investigated (83) with the following conclusions: the intensity of the action increases with the slag concentration; magnesite and chrome show a higher resistance to the action of a basic open-hearth slag; silica shows a higher resistance to the action of acid open-hearth and heating-furnace slags, and a lower resistance to the action of basic open-hearth and blast-furnace slag. From the tables given (83), it would appear as though the action of all the slags used were more severe on chrome than on magnesite. The following tables give the analyses of the materials and the slags used:

Analyses and fusion points of refractory materials

	Diaspore		Fire clay				Silica	Mag- nesia	Chrome
	B	E	A	F	D	C	L	H	I
SiO ₂	30.98	47.94	50.98	57.12	62.20	80.06	96.58	7.80	12.94
Al ₂ O ₃	63.20	47.13	43.94	38.01	33.44	18.30	.74	2.42	23.17
Fe ₂ O ₃	2.62	1.20	3.16	1.94	1.79	.88	.50	3.62	13.45
TiO ₂	3.32	2.15	....	1.97	1.79	1.34	....	....	....
CaO.....	.21	.73	.36	.44	.38	.20	1.88	3.86	.07
MgO.....	Tr.	.11	.52	.50	.25	.07	.16	82.40	8.95
Alkalies....	.46	1.23	1.32	.16	.50	Tr.	....	Tr.	.03
Chr. ox....	....	....	....	....	....	....	....	....	41.24
Total....	100.79	100.49	100.28	100.14	100.35	100.85	100.07	100.10	99.85
Fus. pt. cone....	36	33½	32½	32½	30½	28	31½	....	....

Analyses of slags used

Slag	Basic open- hearth	Blast furnace	Heating furnace	Acid open- hearth	Coal ash
Silica.....	23.32	36.82	16.98	50.16	56.76
Alumina.....	0.30	11.70	3.91	3.00	28.59
Iron oxide.....	26.60	3.40	75.30	30.25	9.25
Titania.....	1.02	0.54	0.70	1.54	1.40
Lime.....	37.95	43.40	0.79	2.32	1.57
Magnesia.....	6.96	2.47	0.14	0.93	0.45
Manganese dioxide...	4.24	0.89	1.89	11.72	trace
Alkalies.....	0.09	0.57	0.06	trace	1.34
Total.....	100.48	99.79	99.77	99.92	99.36
Fusion point—cone...	7	3	2	12	8

Electrical Resistivity:

Brace (37) states that at temperatures from 439°C. to 990°C., electrically-fused magnesia was found to have a higher electrical resistivity than porcelain; that it had a high ratio of initial to final resistivity at each temperature; and that its resistivity comes to a steady value more quickly. Northrup (6) gives the following figures for the electrical resistivity of electrically shrunk magnesia to which 10 per cent MgCO_3 had been added for bonding:

Temperature in deg. C.	Resistivity in ohms per c.c.
1,060	420,000
1,100	320,000
1,170	62,000
1,230	24,000
1,352	510
1,386	415

Howe (90) gives the following values for the electrical resistivity, in ohms per cubic centimetre:

Temp. deg. C.	Magnesia brick	Chrome brick	Silica brick	Fire- brick	Carbor- undum
600	.....	.....	.....	21,000	14,600
700	.....	.....	.....	17,000	10,900
800	.....	2,800	.....	13,000	7,800
900	.....	760	.....	9,000	5,400
1,000	.....	420	.....	6,600	3,700
1,100	.....	430	.....	4,400	2,100
1,200	.....	450	.....	2,300	1,300
1,300	6,200	410	9,700	1,300	960
1,400	420	320	2,400	690	650
1,500	55	.....	710	280	.....
1,550	30	.....	22	60	.....
1,565	25	.....	18	.....	.....

Thermal Conductivity:

Among the many investigators who have studied the thermal conductivity of refractories are Dudley (38), Goerens and Gillis (39), Heyn (40), Dougill, Hodsman and Cobb (41), Tadokoro (42), Hutton and Beard (43), and McDowell and Howe (6). The last named conclude that the thermal expansion of magnesia brick under load does not differ appreciably from the expansion under no load. They give the following table for the thermal conductivity, etc.:

Material	Fusion point, deg. C.	Fails under 50 lb. per sq. in., at deg. C.	Thermal conductivity at 1,000°C.	Specific heat at 100°C.
Fireclay.....	1,700	1,350-1,400	0.0039	0.199
Silica.....	1,700	1,600	0.0044	0.219
Magnesia.....	2,165	1,480	0.0079	0.231
Chrome.....	2,050	1,425	0.0057	.....
Bauxite.....	1,785	1,350	0.0039	.....
Zirconia.....	2,575	1,510	low	.....
Carborundum.....	2,240	1,650	0.0231	0.198
Alundum.....	2,050	....	high	0.186

Silica and clay brick are better conductors hot than cold, while the conductivity of magnesia seems to decrease with the rise in temperature.

Thermal Expansion:

Norton (89) has gone into the subject of the thermal expansion of refractories in great detail, and his work should be of much value to all who are interested in refractories. He concludes that:

(1) The tendency of a brick to spall, other things being equal, is proportional to the coefficient of linear expansion. The coefficient in most cases varies with the temperature, so that it is necessary to pick out the temperature at which spalling occurs. This has been found by observation to lie between $300^{\circ}\text{C}.$, where the thermal strains begin to become serious, and $700^{\circ}\text{C}.$, where the plastic flow is believed to commence in most materials. Usually the maximum coefficient for the whole temperature range lies between these limits, which alone would account for spalling at these temperatures. The non-spalling possibilities of a given material can therefore be judged by the maximum coefficient of expansion between these two temperatures.

(2) Nearly all refractories are composed largely of crystals, which may have two or more allotropic forms, each of which is stable over a certain temperature range. The inversion of a crystal to another form is usually accompanied by a change in volume, which is sharply indicated by the expansion curve. Thus the expansion curve indicates the form and the relative amount of the crystal components. Also, in studying new material, these discontinuities in the expansion curve are an aid in studying that material.

(3) The total amount of reversible expansion determines the size of the expansion joint needed in wall construction. In the construction of crown or roof, a material with a low coefficient of expansion is desirable to prevent the pinching of the ends of the blocks.

Specimen number	Type of brick.	Melting point	Firing temp.	Mean. coeff. of exp. $\times 10^{-7}$ between 300°C. and 700°C.	Max. coeff. of exp. $\times 10^{-7}$ between 300°C. and 700°C.	Max. Ir-reversible contraction or exp. up to 1,700°C.	Inversion points	Changes in slope of curve	Temp. at which shrink. or exp. begins	Order of resistance to spalling	Order of resistance to shrinkage
1	Silica.....	1,700	.....	83	1,000	1%	260°	1,400°	1,550°	15	9
2	Kaolin.....	1,740	1,300	47	79	1%	260	.....	1,050	..	..
3	Kaolin.....	1,740	1,430	68	87	1%	260	.....	1,380	..	..
4	Kaolin.....	1,740	1,500	53	70	1%	260	.....	1,580	..	..
5	Kaolin.....	1,740	1,620	43	67	1%	..	.....	1,610	3	5
6	Fire clay.....	1,720	.....	54	80	large	600	.....	1,300	8	14
7	Fire clay.....	1,680	.....	51	64	-5%	600	1,250	1,250	8	14
8	Fire clay.....	1,700	.....	54	174	large	260	.....	1,220	8	14
9	Fire clay.....	1,610	.....	45	80	-3%	..	.....	1,100	8	14
10	Silicon carbide..	2,000	.....	43	48	0	..	.....	1,700x	2	1
11	Zircon (white)...	2,000x	1,650	64	92	large	800	1,400	1,510	7	12
12	Zircon (brown)..	1,935	1,590	42	48	2%	600	.....	1,550	1	10
13	Zirconia.....	2,000x	1,675	59	87	1%	800	.....	1,600	6	7
14	Mullite.....	1,850	1,785	53	82	0	780	1,350	1,700x	4	2
15	Magnesite (pure)	2,000x	1,680	142	151	0	1,430	.....	1,700x	12	3
16	Magnesite (commercial).....	.....	.....	147	210	2%	.....	500	1,440	13	13
17	Chrome (commercial).....	.....	.....	104	124	2%	1,000	1,130	1,540	10	11
18	Spinel.....	2,000x	1,690	76	110	1%	.....	1,200	1,600	9	6
19	Lime.....	2,000x	1,740	138	145	0	1,500	700	1,700x	11	4
20	Alumina.....	2,000x	1,650	77	82	1%	1,180	.....	1,580	5	8
21	Insulating.....	1,650	.....	74	480	large	200	.....	1,050	14	15

x Approximate.

(4) The temperature at which irreversible contraction starts is of considerable importance, as this temperature is very close to the maximum temperature at which the particular refractory may be safely used.

The table on page 18 is reproduced from Norton's work and is worthy of study.

Hot Crushing Strength:

Kowalke and Hougen (32) have investigated the crushing strength of mixtures of magnesia and silica at high temperatures by calcining a pure grade of magnesia in a gas furnace at about 1,500°C., and mixing silica, in the form of quartz, in various proportions. After thorough mixing, the two were ground to 40-mesh and test cylinders formed under a pressure of 1,500 lb. per sq. in. They were then dried at 100°C. and baked at 2,100°C. After cooling, the test cylinders were subjected to a load of 66.5 lb. per sq. in. and heated at a uniform rate of 10°C. until they failed. The following are the results obtained:

Silica content per cent	Average temperature of failure, in deg. C.
0	1,680
3	1,800
6	1,850
7	1,860
7.5	1,870
8	1,845-1,860
12	1,830-1,845

They conclude that the addition of silica to magnesia increases the mechanical load-carrying capacity, with a maximum of 7 per cent to 8 per cent silica, which failed at about 1,870°C. The failure of the magnesia cylinders is slow and gradual, while the mixtures of magnesia and silica always failed abruptly. They also conclude that the superiority of magnesia-silica mixtures over pure magnesia is due to the formation of forsterite, which cements the grains of periclase together, and the failure comes at a temperature when the forsterite softens.

They also investigated the influence of heat treatment during baking of the cylinders with the following results, using the 7.5 per cent silica mixture:

Maximum temperature of baking, in degrees C.	Crushing temperature in degrees C.
1,500	1,570
1,800	1,820
1,850	1,870
2,100	1,900

These data show that increased temperature and duration of baking increase the subsequent strength of the cylinders, but it was observed that prolonged heating above 1,900°C. must be avoided because of the destructive action of carbon upon magnesia at these temperatures.

Various investigators have studied the behaviour of magnesia brick under load at high temperatures. McDowell and Howe (6) stated that brick made from Washington magnesite failed suddenly at temperatures from 1,410°C. to 1,550°C., and that a brick made from a magnesite containing 15 per cent lime began to soften at about 1,300°C. They found that the magnesite containing low lime failed suddenly, while the high-lime magnesite failed gradually. Comparing this with Kowalke and Hougen's observations (32), that the addition of silica to pure magnesite tended to increase the resistance to crushing and altered the form of failure, it would be interesting to investigate the actual influence of impurities on both the method and the temperature of failures of magnesia brick.

Brown (34) states that a brick made of Austrian magnesite set on end and heated with a constant load of 50 lb. per sq. in. failed suddenly at 1,500°C., and that a chrome brick under the same conditions failed suddenly at 1,450°C.

Mellor and Emory (35) found that the application of load to a brick had considerable influence on the temperature of failure, and that a magnesia brick, whose fusion point was

over 1,920°C. when unloaded, collapsed suddenly at 1,500°C. under a load of 50 lb. per sq. in. They give the temperature of failure of chrome brick under load as 1,400°C.

LeChatelier (36) gives the crushing strength of silica brick as over 500 lb. per sq. in. at 1,500°C. LeChatelier and Bogitch (82) give the following table showing the resistance of silica brick to crushing, expressed in kilograms per sq. centimetre:

Temperature, deg. C.	Load, Kg./Cm ²
15	170
520	158
670	150
800	139
950	125
1,050	120
1,200	85
1,320	62
1,460	50
1,540	37
1,600	30
1,700	12

They note that 12 kilograms per square centimetre at 1,700°C. is about ten times the load sustained by the average brick in furnace construction.

Hartmann and Koehler (79), in a series of tests to investigate the transverse breaking strength of several refractories between 20°C. and 1,350°C., found that chrome brick showed the most decided drop in modulus of rupture, followed in order by bauxite, magnesia, fireclay, and silica.

Griffith (19) gives the performances of various brick under the hot-load test as follows:

Silica brick.....	shears	at about	1,600-1,650°C.
Magnesia brick.....	"	"	1,400-1,550°C.
Chrome brick.....	"	"	1,430-1,470°C.
Fireclay brick.....	softens	"	1,300°C

Mellor and Emory (35) conclude that the collapse of bricks is due to (1) fusion due to gradual melting of matrix, and (2) mechanical collapse of an abrupt nature.

REFRACTORIES AVAILABLE

Dolomite

Theoretically, dolomite is the double carbonate of calcium and magnesium, but there has been no definite line drawn between limestone and dolomite on the one hand, or between dolomite and magnesite on the other. Common usage seems to give the name 'dolomite' to a mixture of calcium carbonate and magnesium carbonate, which has more than 10 per cent magnesium carbonate and, in addition, more than 8 or 10 per cent calcium carbonate. In other words, the dolomite field is taken to include, on one side, a limestone which has more than 22 per cent of the mineral 'dolomite', and, on the other side, a magnesite containing more than about 13 per cent of the mineral 'dolomite', together with the field between.

Dolomite occurs in great quantities at many places, and there has been much research carried on in an endeavour to clear up the question of its exact physical composition, and whether or not it is a definite chemical compound. With this object in view, there has been a great deal of research conducted on the thermal dissociation of dolomite (45).

It is common knowledge that impure limes over-burn much more readily, and at lower temperatures, than the purer varieties, and this line of thought has led many investigators to endeavour to dead-burn dolomite through the addition of such impurities as iron oxide, silica, alumina, roll scale, slag, etc. Due to the fact that lime is more chemically active than magnesia, it is likely that the lime will combine more readily with the impurities than will the magnesia, and it would seem that, if the percentage of lime is not too great, it would be possible to render the lime stable without seriously detracting from the value of the dolomite as a refractory; it might conceivably be possible to form compounds which would be of rather a refractory nature in themselves. With dolomite containing a large proportion of lime, however, it would seem unlikely that enough impurity could be introduced to render the lime inactive without impairing the value of the material for refractory purposes.

The presence of iron seems to accelerate the formation of periclase, and it is likely that small quantities of iron oxide will be of advantage for this purpose, although it may be found that other elements will have the same effect. The silica content requires very careful consideration on account of its property of causing disintegration, when in the form of calcium orthosilicate, but, when combined in other forms, it would seem to be of use in facilitating sintering.

Even if there is discovered a combination of impurities which will render the lime absolutely stable, it seems unlikely that the higher-lime dolomites will ever be as efficient for refractory purposes, under service conditions, as the magnesite or the low-lime dolomites, due to the difficulty in forming a dense, thoroughly shrunk body which will resist erosion and corrosion at high temperatures.

Previous to 1914, comparatively little dolomite was used for the construction of the bottoms in basic open-hearth furnaces in America; magnesite was generally used for this purpose, and dolomite used for temporary patch work. During the war, however, it was found necessary, owing to the scarcity of magnesite, to use dolomite to a much larger extent. Since 1920, the tendency seems to have been to return to the use of magnesite for the construction of bottoms and for major repairs, and to use dolomite for minor repairs and maintenance.

The dead-burning of dolomite is carried out in England in vertical kilns 6 ft. to 8 ft. in diameter, and about 30 ft. high (46). The broken stone is charged in alternate layers with coke, and air is then blown in under a pressure of about one pound per sq. in. It is said that 30 to 60 per cent of the weight of the stone is required to complete sintering with the use of coke as a fuel. In America, it is general practice to use rotary kilns for the burning of dolomite, and McDowell and Howe (9) stated that the rock is usually crushed to pass a 1/2-inch screen, after which the fine powder is removed and the coarser material burned, resulting in a material from which

practically all the carbon dioxide has been driven off. They give the usual range of composition of the crude ore used in the manufacture of dolomite as follows:

Silica.....	1	to 7%
Alumina and Iron oxide }	.....	0.5 to 9%
Lime.....	28	to 35%
Magnesia.....	14	to 20%
Carbon dioxide.....	43	to 46%

They stated that as high a magnesia content as possible is considered desirable.

A special product called 'double-burned dolomite' is said to be manufactured by heating the crude material in one kiln to a sufficiently high temperature to drive off most of the carbon dioxide, and then passing it through a second kiln operating at a much higher temperature.

Most calcined dolomite slakes readily on exposure to moisture, and for this reason a dolomite bottom is likely to show considerable disintegration, if the furnace is shut-down for any length of time. It is also difficult to keep the material in stock without deterioration. This disintegration of dolomite has been ascribed (7) to the following causes:

(1) Disintegration due to slaking by taking up moisture. This is the common cause of the action which is likely to take place when a furnace is shut-down or material kept in stock for any time. The free lime in the dolomite takes up water to form a hydrate, and the increased volume caused thereby disrupts the material.

(2) Disintegration due to the inversion of the ortho-silicate from one form to the other. This inversion seems to cause about a ten per cent change in volume, and starts at about 675°C. In his work on dolomite, Schurecht (8) found that blast-furnace slag used as a flux caused much dusting, and that flue dust, kaolin, basic open-hearth slag, roll scale, and pure iron-ore caused dusting, in decreasing amount in the order named.

Owing to the fact that there are very large deposits of crude dolomite available, and to the comparatively high price of magnesite, there has been much work carried out by various investigators in the last few years with a view to

overcoming the defects to which dolomite is subject, and improving it for use as a basic refractory. Probably the most extensive of these researches is that being carried out by the United States Bureau of Mines in co-operation with the Carnegie Institute of Technology. This work is not yet complete, and it will probably be some time before the results are available.

There are, however, quite a number of synthetic materials, with dolomite as their base, now on the market. These are usually prepared by crushing the crude rock and either mixing it with various fluxes before sintering, or burning the crude rock at a high temperature, and then treating it with various materials. In the first practice, the endeavour is to render the lime inactive by combining it with other elements; in the second, to so coat the grains of dolomite as to prevent it taking up moisture and slaking. One such material is said to be prepared by grinding together dolomite and iron-ore and burning the mixture at a temperature of about 2,850°F. Another product is obtained by grinding together dolomite and about 10 per cent basic open-hearth slag, and burning the mixture at about 2,800°F.

Townsend (5) gives the following analyses of some of these prepared dolomites:

Material	SiO ₂	R ₂ O ₃	CaO	MgO	MnO	CO ₂
Magdolite.....	5.77	6.12	51.05	35.05	....	0.82
Magnite.....	1.35	1.52	59.70	37.77	....	0.50
Madgebrent.....	1.84	8.17	56.86	31.26	0.20	0.51
Dolite.....	2.20	0.86	57.37	38.16	....	0.85
Syndlag.....	4.66	6.18	52.80	31.76	0.98	0.51

Another prepared dolomite is stated to have the following analysis: SiO₂, 11.72; R₂O₃, 10.74; CaO, 44.98; MgO, 31.10; and CO₂, 1.47.

Hofman and Mostowitsch (102) conclude that in pyritic smelting, magnesium ferrite does not form at a temperature as high as 1,500°C., and hence that the richer the dolomite is

in magnesia, the more resistant will it prove to slagging. Also that in basic-steel processes, magnesia resists the corrosive effect of ferruginous slags much better than does lime.

Dolomite brick have been made and used in Europe for many years, and the practice continues to a limited extent to the present time. They are very often made with tar as a bond to take care of the form of the brick during manufacture. The great difficulty is to get a permanent bond, which will overcome the tendency of the lime to slake, and at the same time stand up under high temperatures.

Dolomite, as ordinarily burned, still contains a varying percentage of carbon dioxide, and due to the fact that it is not always used immediately, it may, when charged to the furnace, contain a very high percentage of carbon dioxide and moisture. When thus used in a basic open-hearth furnace it seems reasonable to expect that it will give off a certain amount of carbon dioxide and moisture, and, as a result, will disintegrate to a certain extent. The dust resulting from this disintegration is likely to be picked up by the gases and carried along with them, causing a certain amount of injury to the furnace structure and filling up the checkers. This action will, of course, be very much greater with the material containing the highest amounts of carbon dioxide and moisture.

McDowell and Howe (9) suggest also that this driving-off of moisture and carbon dioxide under the action of heat in the furnace may interfere with the proper setting of the material to a dense mass, and thereby decrease the resistance to erosion. There must also be considered the extra fuel required to cause the evolution of carbon dioxide and moisture, and the quantity of material lost by being carried out of the furnace in the gases, or in the slag. These are in addition to the cost of repairs necessitated. All are important points to be studied in their relation to the cost of the refractory per ton of steel produced.

Magnesite

Magnesite occurs in a number of places, and is one of the most important refractories used in the manufacture of steel in basic open-hearth and electric furnaces. It is also used in

the metallurgy of non-ferrous metals. It is usually supplied as a brick, as grain magnesite, or as furnace cement. The grain magnesite is a granular material grading from pieces of $\frac{1}{2}$ -inch size down to fine grains, and is used in the making and maintenance of furnace bottoms. The furnace cement is a fine-grained material used in brick laying.

Dead-burned magnesite is prepared by heating the crude material to a temperature that will drive off practically all of the carbon dioxide, and at the same time cause a sintering of the material. During this burning considerable shrinkage takes place and the material becomes hard and dense. A fair guide to the quality of dead-burned magnesite can be obtained by observing the degree of burning and shrinkage and the specific gravity. Dead-burned magnesite will not slake when exposed to moisture in the air.

The nature of the product is governed by the time and temperature of burning, together with the amount and character of the impurities. For many years it was considered that the crystalline type of magnesite was of use only for refractory purposes, and that the amorphous type was suitable only for stucco and flooring, but recent work on the subject has demonstrated that by careful handling the crystalline type can be used for the preparation of oxychloride cement, and that the amorphous type can be used for refractory purposes.

Austria:

The magnesite deposits of Austria have been described by Rumpf (61), Redlich (62), Cornu (63), Kern (64), and by the Imperial Mineral Resources Bureau (47), and Crooks (104), who give excellent accounts of them, from which much of the data on occurrences has been taken.

“The Styrian and lower Austrian deposits have an advantage in that they are much nearer the Adriatic port than are those of northern Hungary, and it is from them that most of the Austria-Hungarian magnesite hitherto exported has been obtained. They are situated in the region to the southwest of Vienna. The largest and most widely-known deposit in Austria is that found by Carl Spaeter in 1880 at Veitsch, near Mitterndorf, in Styria, while he was searching for manganese ore. The deposit is said to be three-quarters of a mile long, over a

thousand feet in width, and, so far as can be judged, probably extends to a considerable depth. The summit of the Sattlerkogels is about 3,260 feet above sea level and nearly 1,000 feet above the level of the Veitsch works. The magnesite is quarried on the slope of the hill in a series of terraces about 50 feet apart, through a vertical distance of nearly 500 feet. The chief minerals of the Sattlerkogels deposit, as described by Cornu, are magnesite and dolomite. The magnesite is greyish in colour and contains ferrous carbonate, ranging up to 13 or 14 per cent. The Austrian material has a considerable range in composition, as indicated in the following analyses:

Description	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	MnO	CO ₂
Cornu.....	0.26	nil	7.43	0.96	85.53	0.51	.....
“	1.34	2.22	9.96	3.52	90.07	0.76	.....
Kern:							
“ Veitsch....	3.80	....	8.40	2.50	84.20	....	.....
“ Breitenau..	2.00	0.70	5.50	2.80	87.90	....	.....
“ Semmering.	5.10	0.10	5.30	3.00	85.90	....	.....
“ Sunk.....	0.60	1.40	6.80	4.50	85.90	....	.....
“ Salzburg...	2.20	1.10	5.90	2.00	86.70	....	.....
Veitsch.....	0.45	trace	3.65	0.97	43.82	trace	50.44
Breitenau.....	0.76	0.14	5.72	0.32	43.06	0.94	49.81
Dienten.....	5.83	0.48	1.54	4.32	39.54	....	47.99
Jolsva.....	0.74	0.39	3.27	0.20	44.80	....	50.10
Nyustya.....	0.76	0.27	3.43	0.90	45.00	....	50.20
Various.....	8.98	2.07	3.56	1.09	85.25	....	.....
	3.12	4.16	11.56	1.12	78.34	....	.....

“According to Cornu, dolomite is abundant in the Veitsch magnesite deposits; partly as a fine-grained greyish-black rock, and partly in the form of coarsely crystalline and yellowish-white masses (47) (104).

“The sintering temperature varies from 1,400°C., for breunnerite containing a considerable percentage of iron oxide, to 1,700°C., for magnesite low in iron oxide; but however easily the material sinters, it is, according to Horhager, desirable

to carry the temperature up to at least 1,500°C., and this temperature seems to be exceeded as a rule in Styrian shaft kilns. Horhager states that the amount of fuel required to sinter Austrian magnesite is variable and depends on the amount of ferrous carbonate present; but with good flaming brown coal with a calorific value of 6,000 calories, the amount of coal required is from 0.3 to 0.4 tons per ton of sintered magnesia produced. Kern puts the fuel requirements at 0.5 tons of brown coal (calorific value 4,000 calories) per ton of sintered magnesia produced.

“According to L. C. Morganroth (23), kilns of the rotary type have been installed at several places in Austria, powdered coal being used as fuel, but they suffer from the disadvantage of yielding a large percentage of fines.

“Sintering does not destroy the rhombohedral form of the magnesite fragments, and a microscopical examination of the powdered sinters show clearly the characteristic texture that has been described by Cornu.

“The crushed sinter, as a rule, requires to be further dressed to eliminate impurities, as these are far from having been completely removed before sintering. For this purpose, the grains are classified mechanically. Much of the caustic lime or calcined dolomite falls to dust and is easily eliminated in the finest screenings. The coarser grains are readily dressed by hand picking, the light coloured, and therefore readily-distinguished, impurities, such as talc, calcined dolomite, and silica being easily removed in the Veitsch breunnerite. Such included lumps of dolomite are naturally regarded as objectionable by the quarrymen, and have to be eliminated as far as possible, either by cobbing in the quarry, or in subsequent dressing operations, as otherwise the product obtained would contain too much lime. The colour of the dolomite lumps helps the quarrymen to detect their presence. Lime is regarded as an objectionable ingredient in calcined magnesite, and efforts are made to keep its percentage as low as possible in the sintered product. Austrian sinter usually contains a variable but small percentage of lime, which is doubtless due to the presence of dolomite in the raw material.

“According to J. Horhager (65) and A. Kern (64), the quantity of waste rock obtained in quarrying may amount to about two-thirds of the total bulk of the rock. The freshly quarried material is cobbled to free it, as far as possible, from coarse fragments of impurity, such as schist, dolomite, and quartz, and the lumps are sorted.

“The cleaner portions of the rock are reduced to pieces about head-size. Less pure material has to be broken into smaller pieces, of fist-size, and its dressing involves a considerable loss of magnesite in the form of fragments smaller than nut-size, which are too small to be burned in shaft kilns. The raw magnesite is transported from the quarry by aerial ropeways and chutes, to the sintering kilns at the foot of the hill. The finished material is transported from the kilns to the railway at Wartberg by an aerial ropeway over four miles long.

“In addition to the sintering and quarrying operations near Veitsch, there are works at Breitenau, Trieben, Eichberg, and other places. The works at Breitenau are situated at the foot of the Hochlantsh, whose elevation is 5,700 feet. The terrace quarrying method and other working conditions closely resemble those at Veitsch and at Eichberg.

“The Austrian magnesite formation stretches eastward beyond Vienna, where deposits are quarried between Jolsva and Nyustya. These northern deposits are very similar to the Veitsch deposits, and, in spite of their great distance from the Adriatic, there have been considerable exports from Fiume, to which port they were shipped by rail, some 380 miles” (47).

The deposit at Radenthein has been worked since 1908 by United States capital. The British Clay Worker (77) describes the deposit as lying on a plateau at an altitude of 1,700 m., from which the magnesite is transported by an aerial cable 9 km. long to the plant. It is calcined at 1,600°C. to 1,700°C. in rotary kilns. One kiln is 50 m. long with a diameter of 1.8 m., and has an output of 55 tons per 24 hours. Another kiln is 100 m. long with a diameter of 2.85 m., and an output of 200 tons per day. The coal consumption averages 30 to 40 per cent of the output and is introduced in the pulverized form. The stack gases are objected to and must be

carefully purified. There is a brick plant where the sintered magnesite is mixed with 5 to 7 per cent water and pressed into brick under a pressure of 1,000 kg. per sq. cm. before being fired at 1,500°C. to 1,520°C. in a tunnel kiln.

Canada:

Quebec.—The deposits in the township of Grenville, county of Argenteuil, Province of Quebec, were discovered in 1900 by Boshart, who sent a sample to Ottawa for examination. No attempts were made to market the material until 1907, when a company was organized to operate the property. A ten-ton 'Keystone' kiln was erected and work was continued in a small way until 1914. In 1915 operations were greatly enlarged and have continued to the present time.

The ore found in the Grenville district varies from white to grey, and occurs in extensive masses associated with serpentine. The deposits have been intensely faulted, crumpled, and otherwise deformed. They are of early pre-Cambrian age and occur in the major valleys. Wilson (60) estimated that there is in sight approximately 1,170,000 tons, and there are undoubtedly other deposits which have not been uncovered to date.

The rock is mined by open-pit methods at the present time, although the advisability of developing underground work is being considered. The face is sampled and analyzed before blasting in order to make the requisite selection. After blasting, the 'shot' is sampled and analyzed to check the samples from the face. The rock is then loaded into cars, after preliminary sorting, and samples are taken from each car to check the quality. It is then placed in the particular stock-pile for which its analysis shows it to be suitable.

The specifications of the finished product being known, the different qualities of ore are drawn upon in the required amounts to enable the proper finished analysis to be obtained. The ore is again inspected and culled from the stock-pile, after which it goes to the primary crushers. From these it is discharged on to a picking belt for further inspection and sorting by specially trained men, after which it is taken to the secondary crushers. From these it goes to ball mills, where

the necessary additions are made, and thence to tube mills for final grinding and intimate mixing. From the tube mills it is discharged to storage for the kilns.

Rotary kilns are used for the sintering process. Pulverized coal is used as fuel. From the kilns, the clinker is passed through coolers and crushing rolls. It is then screened and loaded on railway cars for transportation.

British Columbia.—Fairly extensive deposits of hydromagnesite (47) have been reported at two localities in British Columbia — near Atlin, and about 90 miles north of Ashcroft.

“The deposits at Atlin are in two main groups — one about half a mile from Atlin wharf, and the other on the southeast border of the town site (60) (104).

“The hydromagnesite is pure white, rather soft, and falls into powder on drying. Some of it is very wet in the natural state, and may lose as much as 22 per cent of water at 105°C., but most of it appears to be fairly dry, except for chemically combined water. Where saturated with water, the deposits are so situated as to be easily drained. The mineral is exposed at the surface, and can be won by open quarrying without the removal of any overburden.

“The largest of the deposits near the wharf covers about 18 acres, and appears to have an average thickness of 2 ft. 8 in. The deposit was sampled in two pits at different depths. One of those pits was in the southeastern portion of the deposit

	Southern pit			Northern pit		
	Depth 4 in.	Depth 1 ft. 1 in.	Depth 1 ft. 11 in.	Depth 4 in.	Depth 1 ft. 4½ in.	Depth 2 ft. 4 in.
Silica.....	1.86	0.90	0.54	1.22	1.96	9.22
Alumina.....	1.67	.10	.17	.67	.14	.94
Ferric oxide.....	.15	.09	.11	.18	.45	.73
Ferrous oxide.....	.60	.45	.64	.63	.65	.78
Lime.....	2.04	.82	.68	1.26	1.50	6.44
Magnesia.....	41.13	42.35	42.19	40.56	41.93	35.23
Carbon dioxide....	35.98	36.10	36.17	35.96	36.04	37.70
Water.....	18.02	18.95	19.05	19.04	17.66	8.20

at a point where the thickness was 2 ft. 2 in.; the other was in the northern part of the body at a point where the thickness was 3 ft. 6 in. The analyses on page 32, of samples collected in these two pits, were made on material dried at 105°C., at which temperature the loss of water varied from 1.50 to 2.64 per cent.

"The deposits on the southeast border of the town site consist of three large bodies of hydromagnesite that lie in shallow valleys depressed 30 to 75 feet below the surrounding country. The mineral here is much wetter than in the deposits near the wharf, and analyses show losses of water up to 21.77 per cent at 105°C. The largest of the three deposits varies in thickness from 1 foot to 5 feet, with an average of 3 feet. Two samples from different parts of this deposit lost respectively 1.21 per cent and 1.18 per cent of water at 105°C., and gave the following results on further analysis:

Silica.....	0.74	3.48
Alumina.....	0.35	2.85
Ferric oxide.....	0.15	0.56
Ferrous oxide.....	0.66	0.81
Lime.....	0.32	0.42
Magnesia.....	42.85	38.94
Carbon dioxide.....	36.35	34.31
Water.....	19.10	18.10

"It is estimated that the two groups of Atlin deposits contain, approximately, 180,000 tons of hydromagnesite, in beds ranging from about 1 foot to 5 feet in thickness. It is reported that about 200 tons of the material was shipped to San Francisco in 1904, and that some went to England. During 1915, a trial shipment of some 500 tons was sent to Vancouver. The district is stated to be easily accessible by way of the White Pass and Yukon railway from Skagway, Alaska, to Carcross, Yukon Territory, and thence by a bi-weekly boat service on Tagish and Atlin lakes.

"The other locality in British Columbia where, according to G. C. Hoffman (50), hydromagnesite occurs in considerable abundance, is near the 180-mile house on the Cariboo road, 93 miles north of Ashcroft, in Lillooet district. At this locality there are three or four deposits, each from 50 to 100 feet

across, standing a foot or more above the level of the surrounding surface, and the hydromagnesite is traceable from one to the other of these deposits over an area of some 50 acres of ground.

"A shaft sunk in one of these deposits passed through more than ten feet of hydromagnesite — 5 feet pure white, 6 inches yellowish, 3 feet pure white, 18 inches yellowish, followed by an apparently thin layer of the pure white — before reaching what evidently constituted the bed of the deposit, *viz.*, a dark-coloured mud containing a few well-preserved shells. On another deposit, a shaft is stated to have been carried to a depth of 30 feet without the bottom being reached."

The material examined consisted of a pure white, somewhat compacted, yet readily friable, aggregate of fine crystalline particles with a few intermingled rootlets. An analysis by R. A. A. Johnston gave:

Magnesia.....	43.71
Lime.....	0.10
Carbon dioxide.....	37.03
Alumina.....	0.02
Ferric oxide.....	0.04
Phosphorus pentoxide.....	0.30
Soluble silica.....	0.38
Insoluble, chiefly silica.....	1.53
Water, with a little organic matter.....	17.70

An analysis of the insoluble portion showed that, of the 1.53 per cent, 1.35 consisted of silica, and 0.10 alumina (104).

"Magnesite has been found in several localities in British Columbia. The following analyses have been published of specimens from an occurrence at Bridge river" (47):

SiO ₂	7.46	4.08
Al ₂ O ₃	0.23	0.59
FeO.....	0.56	.....
Fe ₂ O ₃	0.25	0.95
CaO.....	0.46	3.25
MgO.....	43.42	42.20
CO ₂	47.28	
H ₂ O+.....	0.58	
H ₂ O-.....	0.10	

United States:

Washington.—The magnesite deposits of Washington are of the crystalline type, somewhat resembling the Austrian, except that they are not, as a rule, so high in iron content. They were discovered in 1916 and production reached the peak during the latter part of the war period.

It is stated (10) that diamond drilling on one property has proved the existence of more than one million tons of ore within 300 feet of the surface. Mining is done by both open-quarry and underground methods. The Finch deposit has a length of 1,500 feet and a thickness of 200 feet. It is worked by the glory-hole method, and the waste amounts to about 20 per cent of the total (6).

The following analyses are given:

	SiO ₂ %	R ₂ O ₃ %	CaO %	MgO %	CO ₂ %
McDowell and Howe (9).....	6.5	7.25	3.40	82.5	0.5
McDowell and Howe (6); average, 1918-19, N. W. Mag. Co.....	6.78	7.02	2.11	83.04	.....
Finch deposit.....	1.9	1.0	1.7	45.2	49.7
Red Marble quarry.....	4.27	0.78	1.07	45.02	49.51
White Allem quarry.....	0.46	1.01	0.31	46.23	50.32
Finch deposit.....	3.30	1.0	1.4	44.8	49.3
“ “	4.3	0.8	1.1	45.0	49.5
“ “	0.6	1.2	0.5	46.4	51.0
Various sources.....	7.80	7.04	3.45	81.13	0.58
	6.40	7.38	2.30	84.00	0.50
	6.92	7.70	2.09	82.57	0.72
	5.57	8.18	3.39	.. . .	0.51

The Northwest Magnesite Company, at Chewelah, is probably the largest producer in the State of Washington, having an installation of 5 rotary kilns, each 125 feet long by 7½ feet in diameter, with a total rated capacity of 9,000 tons of dead-burned magnesite per month. The rock is quarried by the glory-hole method, and after being blasted down from the face is broken with sledges to one-man size stone. It is then dumped into chutes from which it is gathered by cars on a lower level. It is given a preliminary crushing and then

transported by aerial tram to the calcining plant 5 miles away. At the plant it is crushed and ground to about 10-mesh and mixed with 2 to 2½ per cent of iron-ore. It is then taken to the rotary kilns, which are heated with pulverized coal. The fuel consumption is stated to be about 800 lb. of coal containing 13,000 B.t.u., per ton of dead-burned magnesite. From the kilns the material passes through rotary coolers and then through rolls and screens of ¾-inch mesh (6).

California.—Large deposits of magnesite of the amorphous type occur in various places in the State of California. These were utilized to a small extent before 1914 for the production of calcined magnesite for plastic work. Since 1914 the production has increased to a very large extent and the product is being used both for plastic and refractory purposes. The main deposits are in Tulare and Napa counties.

Typical analyses are as follows:

	SiO ₂	R ₂ O ₃	CaO	MgO	CO ₂
Porterville, Tulare county.....	2.28	0.29	1.32	45.17	50.74
Red slide, Sonoma county.....	7.67	0.55	0.04	43.42	48.08
Red Mountain, Santa Clara county.....	0.73	0.35	0.40	46.61	51.52
Winchester, Riverside county.....	4.73	0.20	0.43	44.73	49.40
Napa.....	2.43	2.40	1.57	43.62	50.11
Porterville.....	0.80	0.20	1.02	45.94	51.30
	3.25	2.20	1.25	43.87	49.53
	5.18	1.10	3.34	41.92	48.78
	1.10	0.40	Tr.	46.54	51.20
	3.86	0.80	2.04	43.47	49.48
Various sources.....	1.55	0.45	1.38	45.68	50.97
	6.52	4.80	2.84	84.96	.48
	6.53	7.24	2.85	83.38	.02
	1.60	0.34	0.56	97.06	.16

The general practice in California seems to be to use bottle-shaped and vertical kilns, although recently rotary kilns have come into use. The shaft kilns produced from 7 to 12 tons in 24 hours, and the rotary kilns produce from 60 to 75 tons per 24 hours. The rock for use in the rotary kilns is crushed to 1½-inch diameter and finer, while for the shaft kilns it is usually of larger size.

The fuels used are crude oil, coke, and distillate. It is estimated that the consumption of crude oil in rotary kilns is from one to $1\frac{1}{2}$ barrels per ton of magnesite produced. In one vertical kiln it was stated (6) that 320 lb. of coke are required per ton of dead-burned magnesite produced.

The transportation of the material from the plant to the railroad is in many cases a serious factor in the cost of production.

A rotary kiln installation in Porterville county, California, is described by Bradley as consisting of one 50-ft. by 5-ft., and one 75-ft. by 6-ft., rotary kiln. The kiln feed is half-inch stone. The ore is in the kiln for two hours and the production is 65 tons per 24 hours with a fuel consumption of 1.20 barrels of oil per ton of finished product.

The 'Scott' furnace is also used, and gives a fuel efficiency of 44.5 per cent using fuel oil atomized with steam, as compared with an efficiency of about 40 to 45 per cent for stack kilns and 25 to 35 per cent for rotary kilns; 163 per cent excess air is used, and the furnace is said to be run with unskilled labour (Riddell and Schuette).

Chinese Empire:

Manchuria.—In 1913 there were discovered (69), in southern Manchuria, large deposits of crystalline magnesite situated near the South Manchurian railway in the Province of Sheng-King. These deposits are owned by the South Manchuria Railway Company, and were first observed by Rictshofen in 1869, but were not recognized as magnesite until 1913, when Yoshiawa (70) discovered them near the railway station of Sha-Kang. The magnesite occurs in conjunction with talc and dolomite, and Niinomy (69) estimates that there are probably over two million tons of magnesite in the area. A calcining plant has been erected at Pan-Lung-Shin, and a dead-burning plant at Dairen. Analyses of the various deposits are given as:

Deposit	Sp. Gr.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	CO ₂
Magnesite:							
Kuan-ma-shan	3.00	1.27	0.08	0.20	3.09	44.05	51.31
“ “ “	2.99	3.98	.17	.53	6.39	40.45	48.23
Niu-hsin-shan.	3.00	.70	....	1.19	.30	47.02	50.79
“ “ “ ..	2.99	1.50	.46	.77	1.67	45.68	49.92
Pai-hu-shan....	3.00	2.06	.04	1.04	.90	45.02	50.90
Ta-ling.....	2.99	.78	.32	.50	1.15	46.69	50.50
Nan-ta-ling....	2.98	.70	.51	.20	.42	47.02	51.12
Dolomite:							
Kuan-ma-shan.	2.87	.27	.02	.65	30.23	21.26	47.57
Niu-hsin-shan.	2.86	.56	.20	.72	30.12	21.86	46.55
Ta-ling.....	2.93	.88	.04	1.06	18.20	30.64	49.14

Norway:

“A deposit of white spathic magnesite (47), fairly free from ferrous carbonate, occurs and is worked at Snarum in the Modum district of southern Norway. It is about 35 miles from Drammen and is conveniently situated for shipment either to the latter port or Christiania. The magnesite is found in veins averaging 13 feet thick, in a mass of serpentine, which is associated with schists and quartzites. The magnesite contains serpentine, which is used in admixture with the magnesite for sintering and brick making, and the bricks are stated to be superior to Austrian brick in their refractory qualities. A characteristic feature of the Snarum magnesite is the absence of lime. The following are analyses of Snarum magnesite and of a brick made from it:” (47) (104).

	Magnesite	Brick
Magnesia.....	47.29	83.6
Silica.....	?	9.3
Alumina.....	....	2.0
Ferric Oxide.....	0.79	4.6
Carbon dioxide.....	51.45	....
Specific gravity.....	3.02	....

Italy:

Magnesite occurs in various places in Italy, and on the island of Elba. Some published analyses are as follows:

	Elba	Castiglioncello	Monterufoli
Silica.....	8.9	3	1.07
Fe and Al oxide.....	...	2	2.63
Calcium carbonate.....	...	5	9.60
Calcium oxide.....	1-3.5	..	.....
Magnesium carbonate....	...	89	86.02
Magnesium oxide.....	41-42	..	.....
Carbon dioxide.....	44	..	.....
Water... ..	3-4	..	.....

"The Castiglioncello deposits are in the commune of Rosignano, Maritimo, within a mile of the railway, and consist of large veins varying in thickness from 3 to 10 metres and up to one kilometre long. Large quarries were opened in 1914, and calcining kilns have been erected since that date. Transportation to the kilns is by light-railway and road.

"The Monterufoli deposits are in the Province of Pisa, and occur in veins of from 4 to 8 metres thick in conjunction with serpentine and quartz. The impurities are removed as far as possible by hand cobbing, and the cobbled rock is hauled by carts about 2½ kilometres to the railway. From there it is taken by rail to Ardenza and thence by cart to Montenero, where it is calcined in Dietzsch furnaces" (47) (104).

Greece:

The Grecian deposits have been described in detail, by the Imperial Mineral Resources Bureau (47), from whose monograph the particulars given below are abstracted (104).

Previous to the war, Greece supplied the major portion of the world's requirements of the amorphous variety of magnesite, which, on account of its low percentage of iron oxide, was used chiefly in the manufacture of magnesia cement. Germany was the chief consumer, using 50 per cent of the

production. Most of the deposits so far exploited in Greece lie in the northern part of the island of Eubœa, where there is a belt of serpentine 6 to 9 miles in width and 15 miles in length. The magnesite occurs as white compact masses in the form of veins, lenticles, or irregular masses in serpentine. The width of the bodies varies from $6\frac{1}{2}$ feet up to 130 feet, and the greatest length so far observed in a vein is 500 feet.

The greatest depth at which deposits are worked to-day in Eubœa is about 660 feet, which depth has been reached in the Mantudi mine on the northeast coast of the island. The average depth of mining operations elsewhere does not exceed 200 feet.

The more important of the Eubœan magnesite deposits may be classed in three groups, as follows:

(1) The Limni-Galataki group, situated on the southern side of the serpentine belt. These include the Limni community mine, and the deposits of the Galataki concession.

The distance of the Galataki concession to the loading port is 9 miles by railway (2-foot gauge) and 4 miles by rope line. The rope line is worked on the double rope system, and is capable of conveying 200 tons of mineral per working day of ten hours.

(2) The Mantudi-Pyli group, situated on the northeastern coast of the island. The port of shipment for the Mantudi concession is Kymassi, which is connected with the mines by means of a 2-foot gauge railway, $2\frac{1}{2}$ miles long. A rope line connects the two outlying concessions of Plakaries and Yerorevma with Mantudi.

The port of shipment for the Haghia Triti, Maccas and Stavros mines is Pyli, which is connected with the mines by a rope line capable of transporting 100 tons per working day of ten hours. This rope line is $3\frac{3}{4}$ miles long, with an intermediate station at Maccas and Stavros, nearly two miles from Pyli bay.

(3) The Chalcis group, situated east-southeast of Chalcis, including the Afrati, Gerakari, and Phylla mines. The transport of the magnesite mined in the Afrati district is by cars to the loading port of Lefkandi, in the Euripo channel.

The Eubœan deposits were formerly worked open-cast, but in recent years underground mining has been resorted to. In the first instance, the method adopted was to work the veins by wide stalls, pillars being left to support the roof, but this has more recently given place to the longwall method of working.

The crude magnesite obtained by mining is hand-dressed by girls, as much serpentine and calcite as possible being eliminated in this way. The hand-dressed raw material is then transported to the ports for shipment, where part of it is calcined. The material to be calcined is, however, still further dressed and broken into lumps of convenient size, before it is fed into the kilns. The material is shipped partly in the raw and partly in the calcined state.

A considerable amount of magnesite has been mined in recent years in Macedonia, on the Chalcidice Peninsula, chiefly at Yerakino.

The following analyses show the general composition of typical samples of Grecian raw magnesite:

	Typical raw Grecian	Mantudi (a)	Mantudi (b)	Mace- donia	Kymi
Magnesium carbonate..	95.70	98.08	97.45	94.10– 98.70	92.05
Calcium carbonate....	2.20	0.80	1.39	trace to 3.00	6.15
Silica.....	1.48	0.30	0.20	0.16–4.00	1.30
Ferric oxide and alu- mina.....	0.60	1.20	1.15	0.20–0.40	0.50

The kilns used in Greece are large gas-fired shaft kilns, and up to a few years ago these were all of the Schmatolla type. In recent years various improvements, including Morgan gas generators, Steiger kilns, and pressure and exhaust fans, have been introduced, the result being to increase the rate of

calcination and reduce the consumption of fuel. Experiments made with rotary kilns of the Fellner and Ziegler types did not meet with great success.

The following analyses show the chemical composition of typical samples of caustic and dead-burned magnesia obtained by calcination:

	Caustic	Dead-burned
Magnesia.....	91.00	90.62
Lime.....	2.50	4.10
Ferric oxide and alumina.....	2.85	1.57
Silica.....	2.55	3.00
Moisture.....	1.10	0.71

The production of caustic magnesia requires, on the average, 4.8 cwt. of coal per ton of caustic magnesia produced; whilst, in the old-type of bottle kiln, dead-burning or sintering requires from 6 to 7 cwt. of coal per ton of sintered magnesia produced. The latest type of sintering kiln requires 4.6 cwt. of coal per ton of sintered magnesia produced.

The coal used is in part imported; but the lignite of Eubœa is of good quality and is used to a considerable extent in the calcination of magnesite (47) (104).

Analyses of typical Grecian magnesite are as follows:

SiO ₂	0.20	0.38	1.63	0.90
Al ₂ O ₃	0.20	0.15	0.17	} 0.86
Fe ₂ O ₃	0.20	0.08	1.19	
CaO.....	0.51	1.68	1.44	1.53
MgO.....	47.11	46.09	45.75	45.45
CO ₂	51.77	51.51	49.88	51.26
Total.....	98.99	99.89	100.06	100.00

McDowell and Howe give the following analyses for crude Grecian ore (9):

SiO ₂	0.67	0.46	1.19	1.63	2.28
R ₂ O ₃	0.30	0.50	0.43	1.36	0.19
CaO.....	0.92	1.24	0.80	1.44	1.56
MgO.....	46.06	46.22	45.83	45.75	44.78
Ignition loss.....	52.16	51.51	50.42	49.88	49.76

The following analysis is of brick made in England from Grecian magnesite:

MgO.....	94.74
R ₂ O ₃	2.67
CaO.....	0.60
SiO ₂	1.53
CO ₂	1.34

India:

The mining of magnesite in India has taken place chiefly in the 'Chalk hills' of the Salem district of Madras Presidency, and to a comparatively small extent in Mysore. The magnesite obtained is of the Grecian type (47) (104) (52).

"The 'Chalk hills' are situated 4 or 5 miles to the north and northwest of the town of Salem, in southern India. The Madras railway runs within a mile or so of the deposits, but the distance from the port of Madras is about 200 miles. According to Middlemiss (51) the hills comprise two areas of about $1\frac{3}{4}$ and $3\frac{1}{2}$ square miles. Middlemiss estimated that magnesite constituted from one-third to one-half of the total volume of rock over an area of 620,000 square yards, and about one-tenth to one-sixth over an area of 5,536,000 square yards. The richest portions of the deposits seem at the surface to form hillocks rising to various heights, up to 140 feet, above the plain, so that an almost unlimited supply is available by means of quarrying.

"The following are analyses of a cargo sample, a selected specimen of Salem magnesite as quoted by R. H. Dains (52), and samples of caustic and dead-burned magnesite:

	Caustic	Dead-burned	Cargo sample	Selected specimen
Magnesia.....	96.10	93.12	46.28	47.35
Lime.....	1.03	1.04	0.78	.....
Ferric oxide and alumina	0.44	1.22	0.14	0.30
Silica.....	0.54	4.38	1.17	0.22
Carbon dioxide.....	.....	.....	50.10	51.44
Combined water.....	.....	.....	1.30	0.27
Loss on ignition.....	2.31	0.34	.....	.....

“According to B. H. Brough and E. Kilburn Scott (53), experiments made on a considerable scale with Salem magnesite in the electric furnace yielded a hard, dense product of high refractory quality, which is suitable for the manufacture of brick. Moreover, when powdered and mixed with some adhesive material, it yields a paste and mortar which can be used for the protection of the brick walls of furnaces.

“The mining and burning of Salem magnesite has been dealt with recently in a paper by C. H. Burlton (54). He states that the quarry faces are ‘40 feet sheer’, and that the proportion of the magnesite taken out in development may be about 15 per cent of the ‘deads’, which are removed on tram-lines to dumps. The magnesite is hand-dressed and stacked. The lumps of magnesite obtained by quarrying vary in size from pieces known as ‘lump’, which are double the size of a man’s fist, down to pieces the size of an apple or walnut, which are known as ‘smalls’. ‘Lump-crude’, to which 30 per cent of ‘smalls’ may be added, can be used for calcination in kilns. Smalls are in demand for chemical uses.

“The magnesite is transported by rail to Madras, partly crude and partly in a lightly calcined (caustic) condition. It takes 24 hours to pass the magnesite through the kilns, and three hours through the zone of greatest heat, which is estimated to range from 700°C. to 900°C., and does not exceed 1,000°C. The caustic magnesia is ground so that less than 3 per cent remains on a 120-mesh sieve. To produce one ton of lightly calcined magnesite from 2.2 tons of crude magnesite requires from 0.2 to 0.3 of tons of coal.

“According to D. H. W. Smeeth and P. Sampat Iyengar (55), the only deposits of importance among the various occurrences known in the Mysore and Hassan districts of Mysore State, are those in Dod Kanya and Dod Katur, which are situated between Mysore and Nanjangud. These are vein deposits of the normal type, in serpentine. At Dod Kanya, a patch of serpentine in the Dharwar schists occupies an area about three-quarters of a mile long by one-quarter of a mile wide. The serpentine is traversed by veins of magnesite which vary in thickness up to several feet. The veins tend to be

either horizontal or vertical, and several of the large masses are horizontal, or but slightly inclined. It is estimated that a considerable proportion of the serpentine mass would yield about a ton of magnesite for every 10 tons of rock excavated, and that the total amount of workable magnesite would amount to several hundred thousand tons.

“The following analyses, quoted from the bulletin referred to above, show the composition of magnesite from the Dod Kanya deposit in the Mysore district:

	Impure surface samples		Large sample from stacks	Clean magnesite from different depths			
				3 ft.	6 ft.	9 ft.	12 ft.
Magnesia.....	32.48	40.88	43.52	46.49	45.25	45.84	47.12
Lime.....	16.29	6.56	1.24	0.45	0.48	0.52	0.35
Ferric oxide } Alumina }	0.56	0.57	1.18	0.07	0.12	0.12	0.12
Silica.....	2.44	2.82	5.64	.....	.....	.....	.....
Insoluble residue.	.....	.....	.....	1.78	3.60	2.72	0.75

“On the basis of prospecting work carried out at Dod Kanya, it has been estimated that the probable cost of mining and sorting the magnesite will be from 3 to 5 rupees per ton of magnesite, exclusive of supervision” (47) (104).

Australia:

The magnesite deposits of Australia are, as a rule, of the cryptocrystalline type, and some of the deposits are said to be of considerable size (47) (104).

New South Wales.—Deposits of magnesite occur in New South Wales, near Fifield (56). The magnesite is exposed over an area of about 100 acres, and is said to be white and very pure. The deposit is about 11 miles from the railway.

Queensland.—It is stated that there are extensive deposits of magnesite in several places in Queensland, particularly near Marlborough, Rockhampton, Princhester creek, and Bowen (57). Analyses are as follows (47) (104):

	Mt. Pring.	Kanwararara		Princhester
		A	B	
Magnesia.....	46.00	43.40	46.80	46.90
Lime.....	1.18	0.10	trace	1.50
Ferric oxide } Alumina }	.....	1.50	0.50	0.20
Silica.....	0.90	8.00	2.00	0.20
Carbon dioxide.....	51.72	46.70	50.30	51.30

South Australia.—Magnesite deposits occur in South Australia and are described by Ward (58). They are near the town of Tumby, and occur in the form of regular veins, in thickness up to $4\frac{1}{2}$ feet, with associated hematite. Analyses of South Australia magnesite are as follows (47) (104):

	No. 1 trench	No. 2 trench	No. 3 trench
Magnesia.....	41.83	46.23	43.01
Carbon dioxide.....	46.86	50.99	47.46
Lime.....	1.08	0.24	0.32
Ferrous oxide.....	0.14	0.20	0.19
Ferric oxide.....	0.96	0.20	0.46
Alumina.....	2.03	0.57	2.13
Silica.....	5.56	1.00	5.12
Sodium chloride.....	0.28	0.11	0.18
Water at 100°C.....	0.30	0.16	0.26
Water above 100°C.....	0.94	0.20	0.34
Totals.....	99.98	99.90	99.47

Western Australia.—Magnesite occurs in Western Australia near Bulong, in the northwest Coolgardie district, as veins in serpentine. The area is on the west side of lake Yindarlgoods

and is stated (59) to be over two miles in length and more than 300 acres in extent. It is estimated that a very large tonnage of magnesite could be obtained with a magnesium carbonate content of over 90 per cent. The following analyses are given (78) (47) (104):

MgO.....	47.36	44.96	44.31
CaO.....		1.06	.....
R ₂ O ₃	0.16	0.56	0.42
SiO ₂	0.12	1.12	4.99
CO ₂	51.69	49.33	47.76

South Africa:

The deposits of magnesite in South Africa (48) are of considerable size, are very irregular, and occur in conjunction with serpentine. As a rule the crude magnesite is white and contains inclusions of silica.

“The bulk of the magnesite appears to be used in the manufacture of carbon dioxide, the residue of calcined magnesite being re-calcined by the Union Steel Corporation of Vereeniging. They briquette the calcined magnesite and then dead-burn the briquettes, which are then crushed and made into bricks by burning in special kilns. A typical analysis of South African magnesite is as follows” (47) (104):

Magnesia.....	45.27	per cent
Carbon dioxide.....	39.80	“
Silica.....	2.30	“
Ferric oxide.....	0.80	“
Moisture—110°C.....	0.16	“
Specific gravity.....	2.95	“

Cyprus:

It is stated that there are small deposits of magnesite in the island of Cyprus, although they do not appear to be of commercial importance (47) (104).

An analysis of the dead-burned product, made into brick form, is reported by Dr. J. W. Mellor as follows:

Magnesia.....	87.36	per cent
Lime.....	7.77	“
Silica.....	2.52	“
Fe and Al oxides.....	2.16	“
Carbon dioxide.....	0.21	“
Fusion point.....	1,770°C.	

APPLICATIONS OF MAGNESIA REFRACTORIES

Open-Hearth Furnaces

There are a great many metallurgical practices which are at the present time waiting on the improvement of refractory materials to make possible the betterment of the metallurgical operations. There is, however, very little information or data published as to the specific requirements of refractories in the different parts of metallurgical furnaces, and it is difficult to obtain any comparative information thereon. This is more noticeable with the basic refractories than with the so-called acidic refractories, and is due, perhaps, to the fact that a great deal more research work has been done on the latter than on the former, with the result that the acidic refractories have been developed to a greater efficiency than have the basic refractories.

The different qualities of fire clay, silica, magnesite, dolomite, chrome, etc., all have their places in a furnace, and at the present time they are used in certain places as the result of past experience and because no better materials have been developed for specific requirements.

Better materials for specific conditions can only be developed by an accurate knowledge of the conditions which these refractories may be called upon to meet, and this knowledge must be gained by earnest effort and co-operation between the steel manufacturer and the refractory manufacturer, especially in view of the fact that furnace conditions are so apt to vary in different localities.

The fuels used in the open-hearth furnace are mainly natural gas, producer gas, coke-oven gas, oil, tar, and powdered coal, but there is little data available as to the effect of the different fuels on refractories, compared one with the other. It is, however, generally conceded that, on account of the finely divided ash, among other factors, powdered coal is one of the hardest fuels in its effect on refractories. Fuel-oil, on account of its sharp, hot flame is considered to be more destructive in its action on refractories than the gas fuels, which can be introduced into the furnace with what might be termed a 'soft' flame.

There is so great variation in the type, size, and operating conditions in different plants that it is very difficult to lay down principles which will be applicable to all. Different furnaces in the same plant may even show great variation in their operation, and each separate set of conditions will require treatment varying more or less with the installation and circumstances involved. The quality of the blast-furnace product has undoubtedly an influence on the open-hearth operation, and those open hearths receiving the iron of the most suitable composition for the steel required and the refractories used, will, perhaps, tend to show the best results. The percentage of hot metal charged in different plants may vary within wide limits, and will have an influence on the life of refractories. The quality and quantity of scrap used is not always uniform, and this variation must be taken into consideration. Charging time will vary, depending on the type and size of the furnace, from 40 minutes with heavy melting scrap to 3 hours or more with light and bulky scrap. The limestone used may vary considerably in physical and chemical composition. If it is very compact it will probably take longer to form the slag essential for the proper working of the heat. All these features must be taken into account in preparing comparative data on performances. The quality of the steel produced will affect the operation, as a plant making a very high-grade specialized steel must be more particular in many ways than a plant which has many different uses to which it can put the steel it makes. For instance, the manufacturer of low-carbon, high-quality alloy steels is considerably harder on refractories than the manufacturer of medium-carbon steel of ordinary quality for rolling-mill purposes.

Consideration of the subject might conceivably be divided into two parts: one, the possibility of better and more intelligent use of materials which are at present available in commercial quantities; and two, the possibility of developing refractories which would accord the opportunity for more efficient operation. But the influences tending to cause destruction of the refractories are the same in both cases, so that no attempt will be made here to separate them.

In the normal operation of a basic open-hearth furnace, the gaseous products of combustion are heavily charged with dust, and the action and composition of this dust has been the subject of much thought. Schroeder and Larsen (2), from work which they have done comparatively recently, have concluded that fine oxide particles are picked up from the bath by the stream of combustion gases and carried out with the gases to be deposited in down-takes, checkers, tunnels, and at the base of the stack. They state that the returning current of pre-heated air carries no oxide particles into the furnace. In their work, they state that the molten bath forms enough tiny oxide particles to give the outgoing gases a dust content of a few grams per 100 cu. ft., and that the iron-oxide content predominates, approximating Fe_3O_4 in composition. The lime content varies from 0 to 20 per cent and small amounts of magnesia and silica are present. The lime and magnesia in the dusts are stated to have their source in the dolomite used in the bottom of the furnace, and in the lime or limestone used in the charge.

Below the temperature of 2,550°F. to 2,650°F., the oxide particles simply deposit to form a sintered layer on the brick, as in the checker chamber. On the wall surfaces in a melting chamber, during the first week or so of the operation of the furnace, the porous silica brick absorbs the liquid slag formed from the oxide particles and silica, and recrystallizes into a definite zone structure which has a softening range of from 60°F. to 100°F. lower than that of the original brick. Fluxing is then localized on the saturated brick surface, and the result is the slow corrosion of the walls (2).

In calculating the cost and performance of refractories, every factor must be taken into consideration. This includes, not only the initial cost of the refractory, but the cost of repair work necessitated by the failure of the refractory, the lost time of the furnace due to being down for repairs, the possibility of cutting down time between heats, and the production of steel in a given time.

Cornell (14) gives some very useful data on open hearths, and concludes, in the case of a well known steel plant using 50-ton basic open-hearth furnaces, that each furnace required

a major repair, such as a new roof, or a complete rebuilding, once every four months, the average being 189 heats per roof. He estimates a loss of production, on this basis, of about 3,400 tons of steel per furnace per year, which in itself is a very large total. He does not, however, appear to have taken into consideration an additional loss of production due to the fact that, apart from week-end repairs, there will probably be a great deal of lost furnace-time through the necessary repairs to walls, etc., which do not, as a rule, last as long as do the roofs. These minor repairs will increase the total lost furnace-time by a considerable amount. He gives the following as the approximate requirements of a basic bottom 80-ton open-hearth furnace:

Silica brick.....	141,000	pieces
Magnesite brick.....	20,000	"
No. 1 clay brick.....	250,000	"
No. 2 clay brick.....	84,000	"
Common brick.....	350,000	"
Grain magnesite.....	80	tons.

besides other material in smaller quantities.

One large steel company is stated to have adopted the following standard practice for open-hearth furnaces (14):

1. Fuel — Producer gas, two producers per furnace, each producer to gasify 60,000 lb. of coal per day.
2. Capacity — 100 tons; bath area 650 sq. ft. at the slag line.
3. Bottom — Pan type, with 12 inches sintered magnesite on 12 in. magnesite brick, on 24 in. fireclay brick.
4. Roof — 12 in. thick; body straight, arched in one direction only with 24 in. spring. Only standard shapes used.
5. Doors and frames — Water cooled; doors electrically operated.
6. Buckstays — Slab type, water cooled.
7. Front and Back walls — Supported by water-cooled coolers at the slag line.
8. Ports — Semi-water-cooled type, cooled at vital points.
9. Bulheads — Water-cooled.
10. Air Regenerators — Minimum 68 cu. ft. per ton with minimum 150 sq. ft. of surface per ton; 6,800 cu. ft. and 15,000 sq. ft. standard for 100-ton furnace.
11. Gas Regenerators — Minimum 46 cu. ft. per ton with minimum 100 sq. ft. of surface per ton; 4,600 cu. ft. and 10,000 sq. ft. standard for 100-ton furnace.
12. Valves — Area of gas and air valves ten sq. ft. each.
13. Damper — Cast iron, inclined and air cooled.
14. Stack — 6 ft. diameter, 180 ft. high.
15. Waste heat boilers — to be considered as standard equipment.

The use of tilting furnaces has received much consideration, both as greater producers and as a means of balancing-up plant operations. Cort (66) gives the following comparison, both furnaces being basic and both being drained each tap:

	75-ton stationary	200-ton tilting
Weight of heat.....	82.8	2 ladles—107 tons each
Average prod. per furnace per year....	59,538 tons	110,639 tons
Tons per 1,000 sq. ft. per hr.....	13.9	19.3
Coal used per ton.....	587 lb.	476 lb.
Time of heats, tap to tap.....	12 hr. 7 min.	{ 17 hr. 50 min. 15 hr. 10 min.
Bottom delays, per yr. per furnace....	236 hr. 9 min.	
Charge: Hot metal.....	49.89%	22.30%
Cold ".....	1.73%	.15%
Steel scrap.....	42.84%	76.63%
Ore.....	4.11%	.01%

There is a remarkable difference in the figures given for bottom delays for the two furnaces; this would make a material difference in the maintenance cost. It is misleading, however, to try to compare two furnaces not of the same capacity, and these figures should be taken as indicative only.

Temperatures

Recently there has been considerable attention given by various investigators to the question of temperatures in steel-making furnaces. The subject of the accurate determination of the temperatures used is important, and such data are essential to an intelligent consideration of the different factors involved in the failure of refractories. Larsen and Campbell (3) have gone into this subject very thoroughly and have come to the following conclusions:

Roofs and walls.—"Within the melting chamber the surface of the walls and roof all tend to approach a uniform temperature, because of the radiant heat interchange back and forth between the different wall areas. The range of

temperatures is controlled here at the lower limit by the minimum temperature necessary to melt steel, about 2,700°F., and at the upper limit by the fusing or dripping temperatures of the roof brick, about 2,975 to 3,050°F.

“In slow-working furnaces, the maximum roof and wall temperatures vary from 2,750 to 2,800°F., and in sharp-working furnaces the range is 2,900 to 2,975°F. Most furnaces, however, are overheated sometimes and the brick surfaces reach 3,000 to 3,100°F., which causes fusion in local areas and sometimes over the whole roof and wall surfaces. In the range of steel making temperatures present in the melting chamber, the oxide particles in the gases combine readily with the silica in the brick to form a fluid slag which soaks into the brick or washes off their surfaces.

“As a rule in the upper port ends, the wall surfaces are 100 to 200°F. cooler than those in the melting chamber, but sometimes approach the latter when the flame extends across the bath into the port end. Here also the oxide dusts form a fairly liquid slag with the brick, but on the lower downtake walls and in the slag pockets, the slag is generally cool enough to be viscous and flow slowly down the wall surfaces.

“Maximum top check temperatures vary widely in different furnaces; the range cannot be given accurately, but is probably between 2,300 and 2,600°F. We know, however, that in cool checker chambers, the gases deposit dust in a loosely sintered layer of fine powder, but in very hot chambers the brick often combine with the dust to form a fluid slag, which runs down into the checkers, the top brick being entirely eaten away.”

From the results of their work, it would seem that there is a range of only about 300°F. between the melting temperature of steel and the safe working temperature of silica brick.

Furnace Bottoms

Burned lime, and then burned dolomite, were first tried in the early basic hearths. The next step was to build-in bricks made of calcined dolomite and tar; and later, to ram a

mixture of grain magnesite and tar into place and burn it in. Then followed the present general practice of magnesite brick, protected by a mixture of grain magnesite, sintered into place, layer by layer, with a binder. During the war, when magnesite supplies were cut off, prepared dolomite and double-burned dolomite were used as substitutes for magnesite in the hearths. There are some steel companies who are still using dolomite as the material with which they build their furnace bottoms, but the general trend has been to revert to the use of magnesite, as it became available, for the more important work.

During the war, the following practice was worked out by the superintendent of one of the steel companies in Canada, who stated that he considered such bottoms to be equally as good as those constructed from Austrian magnesite. Crude lump Canadian ore, of the analysis given below, was calcined in a small coal-fired furnace for 8 hours with a coal consumption of about 33 per cent of the weight of the rock used. After discharging from the furnace, the lightly calcined rock was broken down to about $\frac{1}{2}$ -inch fragments and mixed with ground slag in proportions averaging 25 per cent slag and 75 per cent calcines. The mixing was done on the open-hearth floor in the same way as one would mix concrete, with shovels. The furnace to be lined was brought up to a temperature of 2,700°F. to 2,800°F., and the mixture thrown in on the bottom of the hot furnace in even layers, approximately half an inch thick. In this manner the lining was built up on the bottom to the depth required. It was stated that a 75-ton basic open-hearth furnace could be bottomed in this manner in four days, as compared with from 7 to 8 days using ordinary methods. The following analyses were given:

	B.O.H. Slag	Crude ore	Composite
Silica.....	17.29	3.68	11.3
Fe and Al oxides.....	11.59	1.40	6.3
Lime.....	51.97	10.51	33.5
Magnesia.....	6.74	36.26	45.5
Carbon dioxide.....	.....	48.15	.....
Manganese oxide.....	5.67	.....	2.4
P ₂ O ₅	2.70	.....	1.0

It is stated (75) that in South Africa a dolomite containing 10 per cent flux is used in the Transvaal iron and steel furnaces. The dolomite, without calcination, is crushed to a coarse powder and spread over the bed of a heated furnace in a bath of molten iron. For use in electric furnace bottoms, dolomite is said to be dead-burned, ground to 4-mesh, and mixed with melted tar.

The general practice at the present time seems to be to lay magnesite brick or chrome brick on top of a fire brick or silica brick base in the bottom of the furnace. Magnesite is then mixed with a percentage of basic open-hearth slag or mill scale and sintered into place in thin layers on top of the magnesite brick, until sufficient has been added to bring the furnace bottom to its required shape. It is not usual or advisable to use pure magnesite for this purpose on account of the difficulty in properly sintering it into place. With Austrian magnesite, it seems usual to make the mix of 20 per cent to 25 per cent basic slag with 75 per cent to 80 per cent magnesite. The banks are built up in the same way, to the required shape, and are then protected with either crude or treated dolomite.

This practice of adding slag and other impurities to magnesite for use in furnace bottoms had its origin in the fact that, under ordinary conditions, it is impossible to properly sinter the purer grades of magnesite into place, and there must be added to it some binder which will soften at the temperatures used and knit the grains of magnesite together. It would seem reasonable that the very property that makes it necessary to use the slag will be a detriment in the operation of the furnace, in that the slag will be eaten away or fluxed out of the bottom. It would seem likely, also, that, due to the fact that there is so much slag added, and to the fact that the slag is not divided uniformly through the whole body of the bottom, it will be a source of weakness in the finished hearth, and that such action as does take place between the bath and the bottom will be largely due to the slag. Owing to its composition, the added slag introduces into the bottom undesirable compounds, such as phosphates and the metallic oxides, and these, it seems natural, would be a source of weakness when they are in close contact with lime at high temperature.

There is, too, the probability that, if a material which has its acid elements uncombined with lime is used in the construction of a bottom, there will be a tendency for these acid elements to take sufficient lime from the charge to render themselves neutral; and such action, going on in a bottom during the operation of a furnace, would tend to render the bottom more likely to be attacked. It would seem much more advisable, if possible, to have the material rendered absolutely stable before it is placed in use in a furnace bottom. The failure of the hearth through chemical action is detrimental, not only because of the wearing away of the refractory, but because the surface becomes weakened and less resistant to physical action, such as mechanical erosion. As nearly all commercial basic refractories soften at high temperature, and as the slag is much more fusible, the softer the bottom the more rapidly will this mechanical erosion take place (9).

Keats and Herty (73), in their exhaustive study on the elimination of metalloids in the basic open-hearth process, have made certain observations on the action of the slag on the lining of the furnace, and conclude that the erosion of the lining is dependent, for a given amount of slag, on the silica content and the fluidity of the slag. During the working period, the fluidity and iron-oxide content of the slag are controlling factors. They state that the erosion of the lining depends on 5 factors: (1) the amount of slag in contact with the banks; (2) the acidity of the slag; (3) the temperature; (4) the viscosity of the slag; and (5) the iron-oxide content of the slag. The most rapid rate of erosion and corrosion is when the slag is most weakly basic, and at the same time very fluid.

Schurecht (81) concludes that the shrinkage is much less, and the porosity much greater, with magnesite than with dolomite, and that the lime in the dolomite is more actively attacked by roll scale than is the magnesia. This accounts, in part, for the greater resistance of magnesite towards the corrosion of basic slag. He also, in the course of his work, indicates that, on account of its high silica content, blast-furnace slag is not so efficient a bonding material as basic open-hearth slag or roll scale.

McDowell and Howe (9) stated that the erosion of a basic bottom is probably due, among other things, to the chemical reaction between the material in the hearth and the materials in the bath and slag, to the abrasive action of the bath, and to the formation of holes caused by boiling. It seems more likely, however, that the boiling will be largely caused by the holes, and that these will be enlarged by the boiling action rather than caused thereby (103).

When we use burned lime, crude dolomite, calcined magnesite, burned dolomite, or any other material that is not thoroughly shrunk, in an open-hearth furnace, we must take into account that there is a considerable quantity of heat required to complete the shrinkage and that the result is high fuel consumption. It would seem that this work could be done to much better advantage by the refractory manufacturer in the making of his material than by the furnace operator when he is making steel.

The time spent, and labour used, in repairing a hearth is considerable, and it would seem good policy to make all repairs as nearly permanent as possible, in order to cut down the number of such repairs required. Dolomite is largely used for repair work in certain plants, when the hearth has been cut-out in places, due to the fact that dolomite sets-in very quickly; but this practice is questionable in its economy, if the patch does not last as long as would one put in with magnesite, even though the latter took a little longer to set.

Dolomite is used very extensively for the repairs of the slag-line erosion between heats on account of its property of setting quickly, and it is doubtful whether magnesite would be an advantage for this particular work in ordinary steel practice; but for bottoming work it is not likely that, if all the elements were taken into consideration, the use of dolomite would be as economical as the use of magnesite.

The most suitable material for the construction and repair of bottoms of open-hearth furnaces would seem to be one which could be used without adulteration and the consequent introduction of undesirable elements. Several distinct materials, developed for use in the different parts of the furnace under different conditions, might possibly be required, but

it is believed that uniform, homogeneous materials of this nature would show economies in operation over the present general practice.

Roofs and Walls

The roof and walls of a basic open-hearth furnace are constructed, as a rule, of silica brick, in spite of the fact that the acid nature of that material, and its spalling rather easily at certain temperatures, make it far from ideal for such service. It is used by reason of its ability to retain its strength under load to a temperature very close to its melting point, and because its thermal conductivity enables it to conduct heat away from the exposed surface with sufficient rapidity to prevent the general temperature in the brick-work rising above its softening point at ordinary furnace temperatures. These two factors are, however, detrimental to the life and operation of the furnace, as the fact that silica is easily attacked by the basic oxides from the furnace atmosphere tends to cause it to fail much more rapidly than it should, and the high thermal conductivity means that there is an enormous loss of heat through the refractory, thus lowering the thermal efficiency of the furnace. Both these features increase the cost of operation, but silica seems to be the best material available at the present time.

Many attempts have been made to utilize magnesite, chrome-brick, chrome ore, etc., for walls, with varying success. Magnesite and chrome, while very refractory, do not seem to be able to carry the load at elevated temperatures, even in walls where the load is much less than in roofs. Several instances are reported of good results being obtained with lump chrome ore in the lower parts of the walls. At least one firm has more than doubled the length of its wall-life by applying to the silica walls a coating of basic or neutral refractory, which protects the silica brick from attack by the basic oxides in the furnace atmosphere. There have been several types of special refractory brought out for use in furnace walls. One of these is the 'metal-kase' brick, which consists of steel tubes packed with grain magnesite. It is claimed they do not spall nearly as readily as do ordinary

magnesite brick, and that they show an improvement over silica brick for use in certain parts of the furnace. There seems to be a certain lack of agreement as to the results obtained in practice, but their basic nature would make it reasonable to suppose that there would be less reaction with the furnace dusts, and this in itself would make for longer life.

Probably the most successful attempt to overcome the difficulty, in the case of the back wall, has been the 'sloping' back wall, first suggested, it is understood, by Naismith, brick-layer foreman at a South Chicago plant. This consists in bending the buckstays back at an angle from about the level of the slag line. On top of the buckstays are laid $\frac{3}{4}$ -inch plates, and the brick-work from the bottom is continued up on top of the plates to meet the skew, which is brought down to take care of the increased width of the furnace. The brick-work is then covered with sintered magnesite, or rammed tar and magnesite, in the same way as the hearth, and repairs are made to it in the same way as repairs to the bottom.

These are all, however, substitutes for a material with which back-walls, etc., could be built in a normal manner. In the tilting furnace, there is not so much trouble with the back-wall, due to the fact that it is, in reality, a continuation of the hearth, and is repaired in the same way as the hearth, between heats. The other conditions, however, are about the same, except that the front walls are a little more difficult to maintain on account of the fact that, when the furnace is tilted, the front wall is called upon to resist stresses such as obtain in a roof.

The average life of a basic open-hearth roof would seem to be from 200 to 300 heats, while the average life of the acid open-hearth roof is much greater. In a great many cases the appearance of the roof is one of the governing factors in furnace operation, through the tendency of the smelter to drive his furnace until the roof sweats and begins to drip. In other words, he is governed by the refractoriness of his roof. The greater life of a roof in the acid open-hearth furnace may be due to the lower temperature involved, but it is also possible that the fact that, in the basic open-hearth furnace, there are additional basic oxides present in the atmosphere, has a great

influence. It is not unlikely that a basic roof and basic walls would be of advantage in both acid and basic open-hearth practice, since the furnace atmosphere in both cases is likely to be basic.

It is important to determine by observation, for each furnace, the proper height of the roof above the bath, as much longer life is likely to result if the roof is raised or lowered until this distance is such that the best results are obtained (103).

The pressure in the walls is not large, and the load in the silica roof seems to be in the neighbourhood of from 12 to 18 lb. per sq. in. (15). Very often the port wears away unevenly, with the result that the flame is allowed to strike the brick work, causing more rapid destruction. The action of the dust-laden stream of gases is particularly noticeable at the ends where it meets the port and bulkhead structure. The flame may also be forced against the lining by the uneven distribution of a bulky charge in the furnace.

Williams (15) states that the chemical composition of the solid matter contained in the furnace atmosphere is largely iron oxide and calcium oxide. The ratio of these two substances varies in different furnaces, and at different times in the same furnace; the ratio of iron oxide to calcium oxide, in samples of silica brick, ranged from 2 to 1 to as high as 5 to 1, and in samples of checker deposits, from 5 to 1 to as high as 10 to 1. Williams concludes that the slagging action by basic oxides is very important, and he points out the fundamental fallacy of using silica material above the slag line, in either acid or basic open-hearth furnaces.

Schroeder and Larsen (2) have reached the following conclusions in their study of the subject:

- 1—"In the basic open-hearth furnace, the charge and molten metal form enough tiny oxide particles to give the outgoing gases a dust content of a few grammes per 100 cu. ft."

- 2—"Iron oxide predominates in these dusts, varying in amounts from about 50 to 90 per cent and approximates Fe_3O_4 in composition. The lime content varies from 0 to 20 per cent. Small amounts of Mn_2O_3 , MgO , and SiO_2 are present."
- 3—"Lime and magnesia in the dust have their sources in the dusting of burned lime, limestone, and dolomite. The other oxides are formed from the melted bath and metal charge. They are produced by burning and by vaporization during the melting and boiling period. The latter action forms very fine particles which may be characterized as a fume produced by condensation and oxidation of metallic vapours."
- 4—"Below a temperature range of about 2,550 to 2,650°F. (not yet definitely determined), the oxide particles simply deposit to form a sintered layer on fireclay and silica brick; this is the usual condition in checker chambers. On silica wall surfaces above the temperature range (upper port ends, ports, and melting chamber), the oxides flux with silica to form a fluid slag on wall surfaces."
- 5—"During the first week or so of a furnace campaign, the porous silica brick absorb the liquid phase formed from oxide particles and silica and recrystallize into a definite zone structure, which approaches a sort of equilibrium with the furnace atmosphere, and has a softening range of 60°F. to 100°F. lower than the original brick. Fluxing is then localized at the saturated brick surfaces and the result is a slow corrosion of the walls.

"The speed of corrosion varies on different surface areas largely according to their position with respect to the currents of gases in the furnace, varying in proportion to the amount of oxide particles carried to the brick. This surface corrosion may be called the normal mode of deterioration of surface walls.

"The action also occurs on the surface of magnesite, chrome, and other special refractories, but the speed of fluxing is less with the more basic bodies."

6—"The open-hearth furnace operates close to the minimum softening range of the flux-saturated silica walls. In the melting chamber, the surfaces are often over-heated and fused, spalling, fusion, and combinations of these two often cause localized wear in certain areas in addition to the normal wear of fluxing."

7—"Important causes of failures are:

- (a) Roof—Surface corrosion, fusion, spalling.
- (b) Back-wall—Surface corrosion, fusion and mechanical wear in charging.
- (e) Front-walls—Surface corrosion, fusion, spalling.
- (d) Port-end walls—Surface corrosion intensified to a sort of abrasive fluxing action.
- (c) Regenerators—Dust deposition which chokes up checker openings and fluxing action which is more prevalent in gas than in air checkers."

The following table may be of interest; it is given by Graham (80) who analyzed brick from the roof of a basic open-hearth furnace after it had made 135 heats.

	Original brick	Zone No. 1	Zone No. 2	Zone No. 3	Zone No. 4
Depth of zone.....	.....	½ in.	¾ in.	3¾ in.	1¾ in.
Colour.....		red	yellow	black	grey
SiO ₂	95.0	93.7	91.4	85.5	88.6
Al ₂ O ₃	1.1	1.10	1.8	1.5	1.0
Fe ₂ O ₃	1.0	1.14	1.52	5.94	5.52
MnO ₂	trace	trace	trace	0.27	0.37
CaO.....	2.5	3.19	4.10	6.06	4.04
Sp. Gr., bulk.....	1.65	1.78	1.80	2.14	2.14
Sp. Gr., true.....	2.37	2.41	2.41	2.44	2.42
Porosity, %.....	20.4	26.1	25.3	12.30	11.6

Schroeder and Larsen (2) give the following analyses:

Sample	SiO ₂	Fe ₂ O ₃ FeO	Al ₂ O ₃	CaO	MgO	MnO	Total bases	Fusion point (cone)
New silica brick....	94.6	1.9	1.0	1.7	0.3	0.04	4.9	31
Used silica brick (Zone 1).....	86.3	11.6	0.8	0.8	0.6	0.40	14.2	30
Slag drops — roof.....	54.7	40.1	2.0	1.8	0.4	0.40	44.7	10
Stalactites — roof.....	88.8	8.4	1.0	1.0	0.14	0.18	10.7	..

About 16 per cent of the heat supplied to a furnace is lost by radiation from the combustion chamber, and about 7 per cent by radiation from the checkers and uptakes (16); hence a saving of a proportion of this heat would represent an important fuel economy, in view of the fact that not more than about 15 per cent of the heat supplied to the system is used in producing steel.

It should be noted, also, that the life of the roof and walls has a certain influence on the amount of maintenance required in the hearth section, and this should be taken into consideration. The wasting away of the materials in the superstructure will tend to result in a part of the fluxed portions flowing or dripping down on to the hearth and causing trouble. This will necessitate the expenditure of labour and material for repairs to the hearth, which would not likely have been necessary if there had not been this action; so that better wall and roof life would perhaps result in lower hearth maintenance.

It would seem that brick for the construction of roofs and walls should fulfill the following requirements:

- (a) The chemical nature of the material should be such that it will not flux readily with the slag or with the dusts in the furnace atmosphere, *i.e.*, it should be basic.

- (b) The porosity should be as low as possible to prevent the absorption of fluxes, etc., but should not be low enough to increase the spalling tendency.
- (c) The brick should, if possible, be sufficiently refractory to enable their safe use at a temperature of about 3,400°F. or higher, under a load such as is encountered in practice.
- (d) Brick should be, as far as possible, non-spalling.
- (e) Brick should be physically strong and resistant to mechanical action.
- (f) Brick should not be too expensive to enable them to be used to commercial advantage, and the supply should be adequate to meet the needs of the industry.

Ports, Uptakes, etc.

The construction of the port and the refractory used in its construction, have a great influence on the operation of a furnace. The port governs the direction of the flame, particularly with gas fuels, and any wear in the port has a tendency to throw the flame out of line, with possible disastrous results to the roof or walls. Water-cooling has come into use to a great extent, due to the fact that we have no refractory that will give ideal service, but water-cooling has the disadvantage of lowering the thermal efficiency of the furnace, and a refractory is needed which will be suitable for the service without water-cooling.

The upper parts of the end-walls receive severe treatment by reason of the fact that they are in the direct path of the outgoing gases, and the oxides from the furnace are driven against the walls at high velocity. Here again a basic refractory would be advantageous. Schroeder and Larsen (2) give the following analyses:

Sample	SiO ₂	Fe ₂ C ₃	FeO	Al ₂ O ₃	CaO	MgO	MnO	Total
Slag from below air down-take. Talbot basic open-hearth furnace.....	60.7	16.5	7.8	3.5	8.4	1.6	0.8	99.3
Drips from upper section of end-wall, air down-take, Talbot furnace.....	44.3	37.0	8.4	1.2	7.7	1.2	1.1	100.9
Slag on dividing wall, air down-take, Talbot furnace.....	40.1	28.5	9.4	8.8	8.7	3.4	...	98.9
Slag deposit in down-take on 50-ton basic furnace..	45.6	40.5	6.8	4.7	2.9	0.16	0.7	101.4
Slag flowing over wall in down-take of 25-ton acid furnace.....	73.0	19.8	6.0	1.0	1.1	0.2	0.3	101.4

It is noted that limestone was used in the 50-ton basic furnace and burned lime in the Talbot furnace.

The uptakes and slag pockets, etc., are subjected to fluxing and abrasive action by the dusts carried in the gases, and a basic refractory would be of advantage if one could be found to stand up under the conditions of service, and at the same time admit of being insulated. The slag pockets fill with a hard material, and the digging out of the slag often causes considerable loss of time in the rebuilding of a furnace. There are devices on the market for the minimizing of this trouble, such as ladles on buggies in the slag pockets, which can be removed and replaced with little delay; but these require a certain amount of upkeep and do not overcome the damage to the walls. The best remedy would appear to be the prevention of the formation of the slag, or part of it, and this would seem to indicate that basic walls would be of advantage.

Regenerators

The chief cause of failure in the regenerator system seems to be the deposition of dust carried by the gases from the melting chamber. This gradually chokes up the system and to a certain extent destroys the brick by slagging action. As the checkers become filled up with the dust, the working speed of a furnace gradually decreases until a point is reached where repair is necessary.

Schroeder and Larsen (2) state that the fluxing action is more prevalent in gas than in air checkers.

The temperatures in the checkers would seem to range about as follows:

Air checkers.....2,400 to 2,600°F.

Gas checkers.....2,200 to 2,400°F.

Gases leaving checkers.....1,400 to 1,600°F.

The highest temperature is in the upper portions, where the gases enter from the furnace, and here the load is least. Where the load is greatest, at the bottom, the temperature is lowest. Booze (18) estimates that the load on the bottom brick in the average checker would attain a maximum of not more than 6 or 7 lb. per sq. in. He also states that the temperature-change taking place when the draft is reversed is rapid, but covers a narrow range, and he concludes that the stresses tending to cause spalling are of little importance in this instance.

Usually, when checkers are cleaned, the top 8 or 12 courses of brick are found to be damaged to a more or less serious extent by slag. Booze (18) gives the following analyses:

	Slag from air checkers	Slag from gas checkers	Slag from checkers
Silica.....	16.69	24.53	45.75
Alumina.....	23.08	15.36	4.84
Iron oxide.....	45.46	43.92	28.17
Lime.....	11.14	9.77	4.59
Magnesia.....	3.55	1.83	3.44
K ₂ O and Na ₂ O.....	1.57	3.90	.....

Williams (15) gives analyses of materials found in the checkers of a furnace burning oil and melting all-steel scrap charges, as follows:

	Unfused material from checkers	Slag on brick
Silica.....	10.2	40.5
Alumina }	66.3	27.0
Iron oxide }		
Lime.....	4.9	3.4
Magnesia.....	0.9	0.2
Carbon.....	0.07	0.11

Quigley (17) estimates the following life of checkers, under the influence of different kinds of fuel. The values given indicate the number of heats before it is necessary to clean the checkers:

Natural gas.....	300 to 600 heats
Coke-oven gas and tar.....	200 to 300 "
Oil or producer-gas.....	200 to 300 "
Tar.....	175 to 250 "
Powdered coal.....	75 to 125 "

Cornell (14) gives the life of checkers as follows:

Natural gas.....	1,000 heats
Producer-gas.....	500 "
Oil.....	500 "
Powdered coal.....	250 "

It must be remembered, however, in any comparison of such figures, that the location and design of the checkers, slag pockets, etc., will affect the results to quite an appreciable extent, and this influence cannot be disregarded in a study of the subject.

Banks

The banks of the furnace are as a rule eaten away to a greater or lesser extent at the slag-line during each heat, and it is necessary to repair this cutting after each heat. Dolomite

has the property of setting into place quickly, and while it does not make such a permanent repair as does magnesite, it seems usual to use it for slag-line repairs, in an effort to save the time which would be necessary to properly sinter the magnesite into place. If the slag-line is badly eaten away, however, it is necessary to take time to make the proper repair with magnesite. Various mixtures of magnesite and dolomite are used in different furnaces. In electric furnaces, however, magnesite should be used for slag-line repair, if the best results are to be obtained.

In the manufacture of high-grade, low-carbon, alloy steels it has been found, in some plants, that the ordinary fettling with prepared dolomites is not satisfactory, due to the soft alloy steels being kept at a high temperature for a longer period of time in the bath. Very much better results were obtained by fettling with magnesite in these cases.

Ladles

Keats and Herty (73) found that the slag from a basic open-hearth furnace, in its attack on the fireclay lining of a ladle used for ordinary steel, absorbed a considerable quantity of silica and alumina from it, thus decreasing the basicity of the slag, with the result that re-phosphorization of the metal occurred. It would seem, therefore, that it would be an advantage if a basic ladle lining were obtainable, which would minimize the possibility of phosphorus, and perhaps sulphur, returning from the slag into the steel in the ladle.

This point is particularly important in the production of alloy steel, and would seem to merit some consideration. There is also the possibility of action by the steel on the ladle lining, with the result that undesirable non-metallic elements may be mechanically introduced into the metal. Particularly is this true of manganese steel, which has a decided tendency to react chemically with acid ladle linings.

Reaction with the lining, taking place in the ladle, tends to form small particles of slag which theoretically should rise to the surface. With lip-pouring ladles, it was found necessary to keep the slag skimmed off, but this is not satisfactory.

Coffee-pot ladles were developed to overcome the difficulty, but did not wholly prevent it, as the constantly rising particles of slag found their way through with the stream of metal into the moulds. A further development was bottom pouring, but even this does not altogether prevent particles of slag being carried with the metal into the moulds, due to the fact that the strength of the current of metal is greater than the force of gravity.

These particles, which are carried into the moulds suspended in the metal, become fixed in the mass when it solidifies, and the result is a casting containing non-metallic spots or inclusions. They are hard to differentiate from moulding defects, but investigation has shown that many can be traced directly to imperfect ladle linings.

This action can be almost wholly prevented by the use of a basic refractory lining in the ladle, and it is a question whether the continued development of high-grade alloy steels will not make such a procedure more and more necessary.

It has been found that (33) calcined magnesite will slake like burned lime, but the reaction is much slower. This makes an excellent ladle daub for repair between heats, and has been found particularly effective for manganese steel. For certain classes of ingot work it makes a good mould wash.

In practice, for small ladles, a lining of dead-burned magnesite mixed with a binder such as gluten or molasses, with perhaps a little clay, is rammed in and dried. This makes an excellent base for the magnesite wash between heats.

On first thought the cost of magnesite lining for large open-hearth ladles might be considered prohibitive, but for the highest grade of open-hearth alloy steel it may be found that this practice is commercially possible, when the quality of the product is given proper consideration (87).

Water Cooling

Laboratory tests on water-cooled walls (87) tend to show that a layer of refractory material, backed up by a water-cooled structure, will wear away by corrosion and fusion at almost the same rate as if the water cooler were not there, and that the resistance to the flow of heat across the boundary between

the refractory and the surface of the water cooler is such that a wall may be cooled nearly as effectively by exposure to free radiation and air cooling as by a water cooler against the wall. In certain places, the use of drastic water cooling is necessary, because no refractory available will stand up under the conditions obtaining. This is especially true of gas ports, which must retain their shape to give proper combustion and flame direction.

The water cooling of the metal parts of the frame-work, however, is logical, since the cooling medium may be placed in direct contact with the material to be cooled, and both surfaces are of high conductivity (87).

Converters

Dolomite and magnesite have been used in the lining of basic converters. Backhuer (76) states that, for converter linings, a mixture of dolomite and tar is used, containing 35-40 per cent powder, 30 per cent fine grains, and 30 per cent coarse grains, mixed with 8-10 per cent of tar. For the bottoms of converters, a mixture is used of 45 to 50 per cent powder, 25 per cent fine grains, and 25 per cent coarse, with about 12 per cent tar.

In the United States and Canada, the basic Bessemer process is gradually becoming obsolete, except in special circumstances.

Ferro Alloys

Magnesite is used for the bottoming of furnaces in the manufacture of ferro-alloys. Keeney (74) describes a furnace consisting of a steel shell of circular cross-section, 8 ft. in diameter and 7 feet deep, lined with magnesite. The furnace operates at 120 volts, has three vertical carbon electrodes 12 inches in diameter, and produces three tons of ferro-chrome per 24 hours. He also describes another furnace lined with magnesite, manufacturing ferro-manganese, which operates at 72 volts and has a steel shell 18 ft. long, 8 ft. wide, and 7 ft. deep.

Basic linings, preferably magnesite, are much used in ferro-alloy work, which requires a low-carbon and low-silicon in the alloy, and both the brick and the sintered magnesite are used for the increasing demand for such alloys.

Non-ferrous Metallurgy

In a discussion on McDowell and Howe's paper (9), it was stated (13) that the question of basic refractories, and in fact all types of refractories, was usually approached from the point of view of the steel makers alone, but that it should be kept in mind that the non-ferrous metallurgists are vitally interested in the problem of refractories applied to their own practical problems. Refractories which are satisfactory to the steel man are not necessarily so to the non-ferrous metallurgist, and *vice-versa*. The non-ferrous operators do not, as a rule, have to contend with the high temperatures used in the steel industry, and they have radically different conditions in their furnaces. However, they have, in many cases, operations on a large scale in which a high-grade basic lining is more resistant chemically than a siliceous one; and therefore more economical in the long run. The authors (9) state that "the use of the Canadian material is being abandoned by the leading refractory manufacturers" — and throughout the paper it is given a low rating as compared with the low-lime magnesites — but the Canadian material has been found very satisfactory in copper work.

Large quantities of magnesite brick are used in the nickel and copper industries, and since 1911 the larger converters have been almost invariably lined with basic material. Nickel, and some nickel-copper alloys, are refined in basic-lined furnaces.

SUMMARY

The discovery of the basic process for the making of steel, by which certain undesirable elements could be eliminated to a much greater extent than they could in the original method, gave a tremendous impetus to the industry, and the development of the manufacture of steel since that time has been

rapid. The new process, however, necessitated the use of refractories of a chemically basic nature, and increase in knowledge of these materials has not kept pace with the increased efficiency of methods of steel making. The fields of the more commonly used refractories, such as silica, fireclay, etc., have been fairly thoroughly investigated, but there is very little real knowledge of the action of the basic refractories under actual operating conditions and the reasons therefor.

The time is rapidly approaching, however, if it has not already arrived, when the steel manufacturer will be seriously hampered in making further progress in his operations by the lack of better refractories.

The original hearth materials used were dolomite and lime, but the deposits of magnesite in Austria were discovered soon after the basic process was introduced, and the use of magnesite rapidly became general for the important portions of the furnace. Dolomite was still used, however, and its utilization has continued to the present time. When war broke out in 1914, the great bulk of the magnesite used was coming from Austria-Hungary, and it at once became necessary to develop new sources of supply or other materials. The use of dolomite was very greatly enlarged, and there were deposits of magnesite discovered in several countries. Since the Austrian material has again become available, many firms have gone back to the use of magnesite in preference to the war substitutes, but many have, on the other hand, continued to a certain extent with the materials which they used during the period when the Austrian magnesite was not available.

Practice and Operating Conditions:

At the present time the general practice seems to be to use silica brick in the roofs, crowns, walls and general superstructure of the furnace. Magnesite and chrome brick have been tried in the walls, but do not seem to have been successful. Lump chrome ore has been used in the lower part of the walls and in the bulkhead with, it is stated, good results. The hearth, or bottom, is usually built on a foundation of magnesite or chrome brick on top of silica or clay brick. The hearth itself is, as a rule, built of magnesite or dolomite sintered into place with a binder of basic open-hearth slag or roll scale.

The maintenance of the hearth is carried out with magnesite or dolomite, and dolomite seems to be the material most generally used for the repair of the slag-line between heats.

There is very little accurate information available as to the temperature in different parts of the furnace, and this is a factor which must be considered when dealing with the failure of refractories. Possibly the best treatment of the subject is by Larsen and Campbell, of the United States Bureau of Mines, who give a range of finishing temperatures of from 2,725°F., for slow-working furnaces, to 2,975°F., for fast-working furnaces. There was very little difference found between the temperatures of the roof and those of the back-walls at any given time. The temperature of the end-walls may reach the above figure, if the flame is allowed to extend across the bath, but it is usually 100° to 200°F. lower than that of the melting chamber. The maximum temperature in the top checkers is given as about 2,600°F.

The causes of failure of the parts of the furnace are many, and accurate information as to the conditions obtaining is very meagre. The atmosphere of the furnace is known to contain the oxides of iron and calcium. These are both chemically basic in their nature, and it seems inevitable that when these oxides, in the form of very finely divided dust, are driven against the silica walls, roofs, etc., at the temperatures obtaining in practice, there will be a reaction set up which will be detrimental to the furnace structure. This action is described by Schroeder and Larsen as a combination of saturation and solution of the silica brick by the dusts. There is also the mechanical abrasion of the surface by the particles of dust carried by the gases, which must be taken into consideration. The lower wall surface may be attacked by splashes of metal and slag from the bath. The banks are subject to erosion by the slag and require patching after each heat. This action may be either chemical or mechanical, or a combination of both. The hearth is subjected to chemical attack by the slag and to mechanical scouring by the metal in the bath, as well as to damage due to charging cold material. There is a certain scouring action in front of the tap-hole, due to the stream of metal flowing towards the hole. Sudden changes in temperature may cause spalling and cracking of the brick, and

a poorly directed flame, due to failure of refractories in the port structure, may cause overheating of a local area of the walls or roofs. There is also the ever-present human element, which must be taken into account with all the above in a consideration of the performance of refractories in a furnace.

The Cost:

There are so many factors to be taken into consideration in assessing the value of any particular refractory material that it is difficult to arrive at an accurate comparison. The final test of the value is the results it gives in actual service in the furnace under operating conditions, but this service must be measured by very broad consideration of all the factors involved.

The initial cost of the material is not always the most important cost. There are other factors which must be considered. The production of steel in a given time, the loss of production through a furnace being down for repairs, the cost of labour and materials for making such repairs, etc., must all be taken into account. If, for instance, by using a more expensive material for hearth construction and maintenance, it is possible to cut down the time lost in making and repairing bottom, the saving through increased production and decreased cost per ton of steel produced will soon out-weigh the small extra material-cost. The influence of the refractory on the quality of the steel produced must also be taken into consideration. This is especially true in the manufacture of low-carbon alloy steels, where the action is severe and the quality of the product is of prime importance.

Development of Canadian Refractories:

There was practically no basic refractories industry in Canada before the war. When the supply of magnesite from Austria-Hungary was cut off, in 1914, there was a search for deposits in Canada and the United States, from which a material could be produced to take the place of that formerly imported. Deposits were found in the western part of the United States and in the Province of Quebec in Canada, and a start was made in the production of a basic refractory.

At first the crude ore was mined and shipped to existing plants for conversion into the finished product. Some of the ore went to the United States and was there burned to clinker, which was used in the grain form or in the manufacture of brick. One Canadian steel producer calcined the ore lightly and mixed it with crushed slag. This mixture was then used in making up the bottom of open-hearth furnaces and was said to give very good results. Later, the Canadian producers of refractories came to an arrangement with the Canada Cement Company to sinter the ore in the cement kilns of that firm, and this arrangement was carried on until the end of the war.

With the end of the war came the decrease in the quantity of steel required, and the increase in the quantity of Austrian material available. During the rush to produce in war years there had been little time to spend on the study of the product, and there was not the urge for improvement in quality, which was later made essential by the keen competition of imported materials.

In 1922, the two largest Canadian producers pooled their resources in an effort to find a material which would be an improvement over existing products available. It was felt that there was a need for a better refractory for use in the bottoms of open-hearth furnaces, and the first efforts were in this direction.

The first feature to which attention was given was the chemical nature of the material. Available refractories ranged all the way from pure dolomite to the purer types of magnesite. It was decided that, as the Austrian material had been the standard up to that time, it would be wise to start with that as a basis. In the study of the subject it was brought out that a material for use in a basic bottom should be basic in its chemical nature, and should be inert to the action of the elements in the bath and slag, insofar as possible.

A consideration of the Austrian material revealed the fact that the sum of the silica, alumina, and iron oxide was greater than that of the basic elements other than magnesia. It is known that the different elements have a definite affinity for each other and will react with each other under certain condi-

tions. Lime is more active chemically than magnesia, and in the steel furnace, where free lime is available in quantities from the charge, it would seem likely that if the material used in the construction of the bottom had not sufficient lime in its composition to neutralize the acidic oxides present, there would be a reaction set up which would tend to cause disintegration of the refractory, rendering it less resistant to the action of the bath. If, on the other hand, the acidic oxides in the refractory had been made stable by proper combination with lime before placing in the furnace, the chances of reaction between the refractory and the charge would be lowered to a minimum, and in consequence the refractory made more efficient. This was borne out by the following analyses of bottoms:

	(A)	(B)	(C)
Silica.....	2.20	6.60	4.60
Alumina.....	4.05		2.30
Iron oxide.....	11.21		7.77
Lime.....	14.70	19.08	52.00
Magnesia.....	62.83		30.82
P ₂ O ₅	1.85		.....
MnO.....	3.16		2.51

(A) and (B) are samples from an Austrian bottom after it had been in use for a short time. It will be noted that the lime content has risen to a point very much higher than in the original material. (C) is the average of a dolomite bottom which had been in service for some time.

Burned dolomite contains about 45 per cent to 60 per cent lime, and it would seem that, if sufficient acidic oxides were added to render the lime stable, the product would contain so much impurity that it would be rendered useless as a high-class refractory. On the other hand, if the lime were not rendered stable, the dolomite would disintegrate under the influence of moisture, and would also be open to attack by the elements in the charge, due to a large part of the lime being in the free state. There would be a corresponding larger erosion of the bottom during the heat.

There are a number of 'prepared' or 'treated' dolomites on the market and these have their place in the open-hearth; but they, too, contain varying quantities of free lime and are for the most part subject to disintegration.

The purer types of magnesite are, in general, unsuited for refractory use, in that they cannot be thoroughly sintered into place in ordinary commercial operations and must be mixed with slag or some other such material in order to make them workable. This tends to introduce into the bottom undesirable elements, such as the metallic oxides, phosphorus, etc., which may be the source of trouble in furnace operation. The composition of the slag is an uncertain factor, and it seems unfortunate that it should be necessary to incorporate it in a bottom.

The second point for investigation was uniformity. It was generally conceded that modern methods of manufacture call more and more for uniformity of the materials entering into manufacturing processes. Un-uniform materials are a potent cause of difficulties in operating, and are being eliminated as rapidly as possible. An examination of the present practice disclosed the possibilities of great variation in conditions, with the attendant operating problems. Refractory materials are purchased, and these themselves, as a rule, vary within quite wide limits. They are then mixed for use in bottom work with varying proportions of slag, which is not always as uniform in its composition or structure as might be desired. The mixing is done by unskilled labour, and it is liable to variation. The result is that the mixed material, when it enters the furnace, is of most problematical composition. In view of these points, it was at once evident that there existed a need for investigation. A study of this problem seemed to indicate that the only place where it would be possible to ensure thorough and complete blending of the different elements would be in the crude form before sintering. This led to the conclusion that the most efficient refractory would be one with which it was not necessary to mix slag for furnace use, but which could be used pure. If this blending and mixing is left until the material is being placed in the furnace, the natural result will be very uneven distribution of the different elements throughout the bottom, and any weakness of this sort is dangerous in a furnace working at the temperature and under the conditions required for the manufacture of steel.

There is, also, the subject of the physical uniformity of the material. The present practice in bottoming an open-hearth furnace is to mix refractory materials and slag in varying proportions and apply the mixture to the bottom. The result is that the voids in the refractory material are filled with slag, which in itself is not a refractory and is a source of weakness in the finished bottom. If the slag binder is attacked and eaten away, the grains of the refractory are likely to become detached from the mass and enter the bath. The ideal refractory would be one which had the slag, or whatever material is deemed necessary, disseminated in a very finely divided state through the material, and this can only be accomplished by fine grinding and blending before the refractory is burned.

Another point which has an influence on the performance of the bottom is the grain-size of the materials entering into its composition. If there are too many voids, which are later filled with slag, the mass is not likely to have the same density and resistance to attack, as if the grain size of the refractory material were so regulated that only a minimum of voids would remain to be filled with a binder.

Microscopic study of the clinker, etc., has been undertaken, in an endeavour to throw some light on the action which takes place in a furnace bottom during use.

Most of the clinkers and brick were found to be too friable to enable good thin sections to be prepared for examination by transmitted light. Many were tried with disappointing results. Much more satisfactory results were obtained by polishing the furnace-bottom material with abrasive polishing material, using oil as a carrying medium. Water appeared to attack some of the constituents too readily, so it was abandoned. Vertical illumination was used for examination and photographing, as is usual for opaque objects. Furnace-bottom material is usually dense and hard enough to stand up fairly well under the polishing process, and shows characteristic structures on examination. A marked difference between Austrian and Canadian magnesite structures was revealed, as the latter is considerably finer. When burned with open-hearth slag or other bonding material, they still retain their charac-

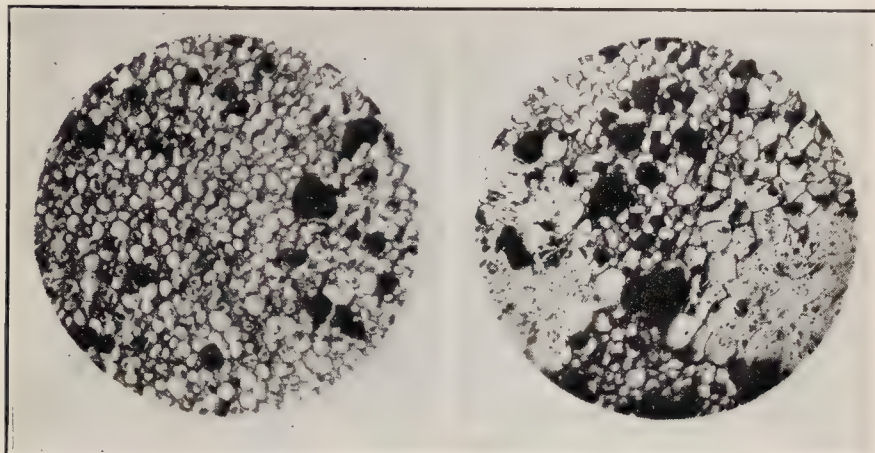


Figure 1.

Figure 2.

Figure 1.—Canadian material and basic open-hearth slag,
12 to 1. $\times 100$ diam.

Figure 2.—Canadian material, Austrian magnesite, and basic
open-hearth slag, 12 to 1. $\times 100$ diam.

Samples polished with oil and abrasives—unetched.

(Canadian Steel Foundries, Limited. Furnace No. 3)

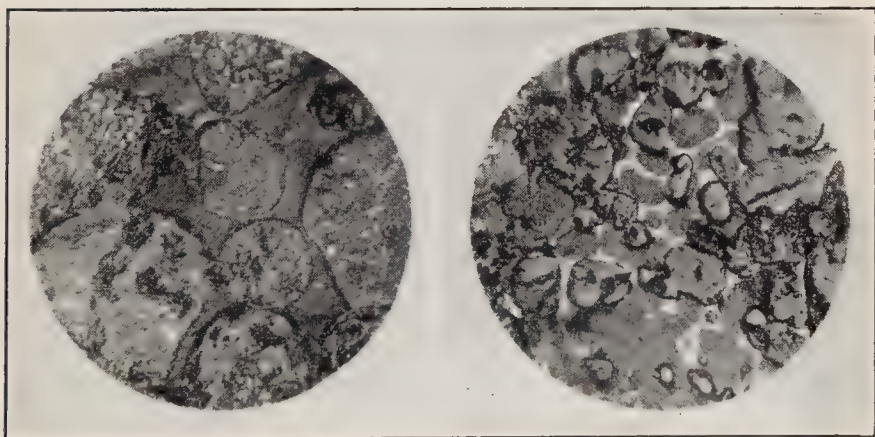


Figure 3.

Figure 4.

Figure 3.—Austrian magnesite and basic open-hearth slag,
12 to 1. $\times 1,000$ diam.

Figure 4.—Canadian material and basic open-hearth slag,
12 to 1. $\times 1,000$ diam.

Samples polished with oil and abrasives—unetched.
Note white constituent in fused areas.

(Canadian Steel Foundries, Limited. Furnace No. 3.)

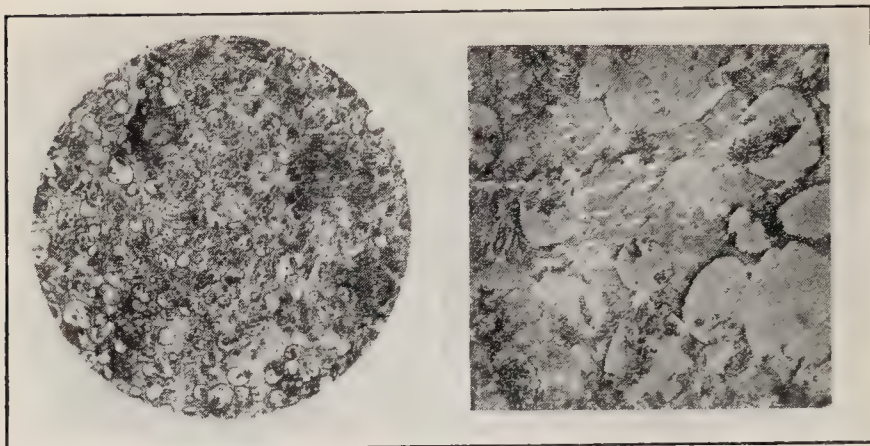


Figure 5.
× 100 diam.

Figure 6.
× 500 diam.

Canadian material and basic open-hearth slag.
Samples polished with oil and abrasives—unetched.
Note the eutectic formation in fused areas.

(Basic open-hearth furnace bottom. J. and L.—Furnace No. 17)

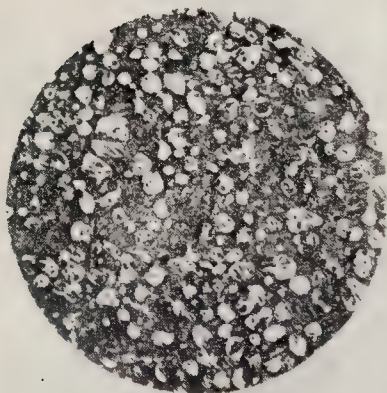


Figure 7.
× 100 diam.

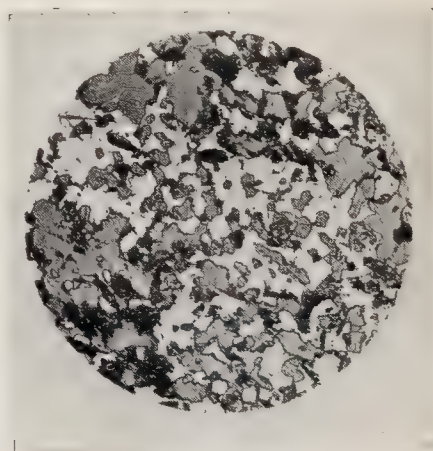


Figure 8.
× 100 diam.

Fig. 7.—Canadian material and basic open-hearth slag.
Sample polished with water and abrasives—unetched.
(Basic open-hearth furnace bottom. J. and L.—Furnace No. 17)

Fig. 8.—Old magnesite bottom, well fused and glassy.
Sample polished with oil and abrasives—unetched.
(Canadian Steel Foundries, Limited. Furnace No. 3)

teristic structures irrespective of the amount of slag mixed with them previous to burning or partial fusion, i.e., within the limits used in open-hearth practice. With increasing amount of slag the proportion of fused material will, of course, be greater, but the structures of the unfused portions do not change much.

Insufficient work has been done to allow full interpretation of the structures revealed in the photo-micrographs, but there is an outstanding difference in the fused portions of the mixture. A white constituent is almost invariably present in the fused portion of the Canadian magnesite mixtures. In one case it was separated out with some of the fused material with well defined eutectic structure. So far, its nature or composition has not been determined. The microscopic examination of furnace-bottom material is being followed out in a systematic manner, as it is felt that much may be learned from it, when more data have been obtained.

Further Investigation Necessary:

There has been considerable work done on the subject of refractories for use in the basic open-hearth furnace, but much more remains to be done.

The action which goes on in a bottom after it is placed in service should be studied, and the influence of different conditions determined. We have evidence to indicate that a bottom put in with a material deficient in lime, for instance, picks this element up until, in certain cases, it has a lime content of about 20 per cent, thus leading to the conclusion that the material has stabilized itself in operation; but we do not know the factors governing the extent of this action. An extended investigation of a bottom put in with Austrian magnesite is in progress, and may lead to some knowledge of the subject.

The development of a basic brick which could be used in the superstructure of an open-hearth furnace is full of possibilities. The present practice is to use silica brick by reason of the fact that they are the most suitable of the materials available. They are, however, of a chemical nature directly opposed to that of the dusts in the furnace atmosphere, which

work for their destruction, and they are subject to spalling at certain temperatures. They seem, however, to be the best available, and we must use them in spite of the fact that the loss in production through lost furnace operating time, due to the necessity for so frequent replacement of walls, roofs, etc., is a very serious factor in plant costs.

If, at the same time, basic brick could be made to operate with safety under higher temperature conditions, the logical result would seem to be a gradual increase in operating temperatures with the attendant increase in production. The average thermal efficiency of the open-hearth is probably about 15 per cent maximum, and the saving which would be made possible by insulation, if we had refractories to stand it, would likely be very large indeed. The greatest gain, however, would probably result from the saving in operating time, and the consequent higher daily production.

In addition, there is the human element to consider. The operation of an open-hearth furnace is at best hot, hard work, and anything that can be done to decrease the time that the operators must spend on the repairing of bottoms, walls, roofs, etc., is likely to increase their efficiency in the actual melting of steel.

Conclusion:

The subject of basic refractories is a very large one, and, in the limited time available, it is only possible to cover it in a very sketchy manner.

The importance of the development of better refractories, especially those used in the production of basic steel, can hardly be over-estimated. The steel manufacturer is badly handicapped by the fact that such refractories as are available to him are not as efficient as they might be.

The production of a material or materials which would give better service in bottoms is worthy of consideration. The development of a brick which would increase the life of walls, roofs, etc., to any extent would be of great help. The making possible of higher operating temperatures would result in economies through increased production, with decreased fuel consumption per ton of steel and lower operating costs.

There is also the possibility of the more intelligent use of materials which are at present available to us, through a better understanding of the conditions of operation. The common aims of the steel manufacturer and the refractory manufacturer are lower furnace upkeep costs, increased steel production per furnace, and increased fuel efficiency, and it is essential, for the realization of these aims, that they work together. The manufacturer of refractories, no matter how willing he may be, cannot reach the objective alone, because of his lack of accurate knowledge of operating conditions.

In conclusion, it should be recorded that the assistance being given in the solution of some of the problems of the industry by the Federal Department of Mines, and the National Research Council of Canada — who have realized the importance of the subject and are co-operating in its investigation — is likely to result in a more thorough understanding of the factors involved. The United States Bureau of Mines is also conducting an investigation which shows promise of providing a more accurate knowledge of the effect of operating conditions on refractories.

BIBLIOGRAPHY

- 1.—Iron Age, 117, 1926, 25.
- 2.—Schroeder and Larsen, Progress Report on the Effect of Open Hearth Process on Refractories; Min. and Met., July, 1926.
- 3.—H. M. Larsen and J. W. Campbell, Optical Temperature Measurements in Open Hearth Furnaces; Pittsburgh meeting of the Amer. Inst. of Min. and Met. Eng., Oct., 1926.
- 4.—Schroeder and Larsen (see 2 above).
H. LeChatelier and B. Bogitch, Reaction of Iron Oxide on Silica; C. P. 166, 764-9, 1918.
W. J. Rees, Study of Silica Products; Trans. Ceram. Soc. (Eng.), 18, 165, 1919.
J. E. Stead, Notes on a Silica Brick from roof of an Open Hearth Furnace; Trans. Ceram. Soc. (Eng.), 18, 389, 1919.
C. S. Graham, A Silica Brick from an Open Hearth Furnace after use; Trans. Ceram. Soc. (Eng.), 18, 399, 1919.
Alex. Scott, Constitution of Silica Brick; Trans. Ceram. Soc. (Eng.), 17, 459, 1918.
- 5.—H. E. Townsend, Rept. Elec. Furn. Assn., 79, Oct. 6th, 1920.
6. McDowell and Howe, Magnesite Refractories; Jour. Amer. Cer. Soc., 3, 190, 1920.
- 7.—Shepard and Rankin, Ternary System CaO , Al_2O_3 , SiO_2 ; Jour. Ind. Eng. Chem., 3, 9, 1911.

518 MAGNESIA REFRACTORIES—CARRIE AND PASCOE

- 8.—R. G. Schurecht, *Jour. Amer. Cer. Soc.*, 2, 304, 1919.
- 9.—McDowell and Howe, *Basic Refractories for the Open Hearth*; *Trans. Amer. Inst. Min. Eng.*, 55, 291, 1919.
- 10.—C. G. Yale and R. W. Stone, *Magnesite in 1917*; *Min. Res. of the U.S.A.*, 1917, part 2.
- 11.—*Iron Age*, February 26th, 1925.
- 12.—J. S. Unger, *Carnegie Steel Co.*—Discussion on (9).
- 13.—F. R. Pyne: discussion on (9).
- 14.—S. Cornell, *Some Considerations Necessary in the Selection of Refractories for the Open Hearth*; *Jour. Amer. Cer. Soc.*, Sept. 20th, 1924.
- 15.—C. E. Williams, *Operating Conditions in the Open Hearth as they affect Refractories*; *Jour. Amer. Cer. Soc.*, Sept., 1924.
- 16.—C. L. Kinney Jr. and G. R. McDermott, *Thermal Efficiency and Heat Balance of an Open Hearth Furnace*; *Amer. Iron and Steel Inst.*, 1922 Year Book.
- 17.—F. B. Quigley, *Open Hearth Furnace Regenerators*; *Amer. Iron and Steel Inst.*, Oct. 25th, 1923.
- 18.—M. C. Booze, *Fire Clay Brick for the Open Hearth*; *Jour. Amer. Cer. Soc.*, Sept., 1924.
- 19.—R. E. Griffith, *Chrome Refractories for the Open Hearth*; *Jour. Amer. Cer. Soc.*, Sept., 1924.
- 20.—H. C. Harrison, *Roof Brick for the Open Hearth*; *Jour. Amer. Cer. Soc.*, Sept., 1924.
- 21.—Thomas and Gilchrist, *Removal of Phosphorus*; *Jour. Iron Steel Inst.*, 14-15, 1879.
- 22.—Harbord and Hall, *Metallurgy of Steel*; 1916.
- 23.—L. C. Morganroth, *The Occurrence, Preparation and Use of Magnesite*; *Trans. Amer. Inst. Min. Eng.*, 50, 1914.
- 24.—R. C. Grosrow, *Refractory Magnesia*; *Met. Chem. Eng.*, 17, 415, 1917.
- 25.—Goodwin and Mailey, *Properties of Fused Magnesia*; *Trans. Amer. Elect. Chem. Soc.*, 9, 89, 1906.
- 26.—C. W. Kanolt, *The Melting Points of Some Refractory Oxides*; *Jour. Wash. Acad. Sci.*, 3, 315, 1913.
- 27.—J. W. Mellor, *Trans. Cer. Soc. (Eng.)*, 16, 85, 1916.
- 28.—E. W. Washburn, *Latent Heats of Fusion of Lime and Magnesia*; *Trans. Amer. Cer. Soc.*, 19, 195, 1917.
- 29.—Fitzgerald and Bennie, *Trans. Elect. Chem. Soc.*, 9, 101, 1906.
- 30.—E. DeM. Campbell, *The influence of the Temperature of Burning on the Rate of Hydration of MgO*; *Jour. Ind. Eng. Chem.*, 10, 1918.
- 31.—R. C. Gosrow, *Refractory Magnesia*; *Met. Chem. Eng.*, 17, 415, 1917.
- 32.—Kowalke and Hougen, *Crushing strength of Magnesia-Silica Mixtures at High Temperatures*; *Trans. Elect. Chem. Soc.*, 33, 1916.
- 33.—G. M. Carrie, unpublished notes.
- 34.—G. H. Brown, *Load Test on Magnesia-Chrome-Silica Brick*; *Trans. Amer. Cer. Soc.*, 14, 391, 1912.
- 35.—Mellor and Emery, *Effect of Load on the Refractoriness of Fire Brick*; *Gas. Jour.* 142, 1918.

- 36.—LeChatelier and Bogitch, Manufacture of Silica Brick; Trans. Amer. Inst. Min. Eng., 60, 134, 1919.
- 37.—P. H. Brace, The Electrical Resistivity of Porcelain and Magnesia at High Temperature; Trans. Amer. Elect. Chem. Soc., 33, 205, 1918.
- 38.—B. Dudley, Thermal Conductivity of Refractories; Trans. Amer. Elect. Chem. Soc., 27, 285, 1915.
- 39.—Goerens and Gillis, The Thermal Conductivity of Refractory Materials; Ferrum, 12, 1, 1915.
- 40.—E. Heyn, Thermal Conductivity of Refractory materials; Stahl und Eisen, 34, 832, 1914.
- 41.—Dougill, Hodsmen, and Cobb, Thermal Conductivity of Refractory Materials; Jour. Soc. Chem. Ind., 34, 465, 1915.
- 42.—Tadokoro, Sc. Rep. Tohuko Univ., 10, 339, 1921.
- 43.—Hutton and Beard, Trans. Far. Soc., 1, 266, 1905.
- 44.—E. Kilburn Scott, Discussion; Trans. Amer. Elect. Chem. Soc., 33, 258 1918.
- 45.—Shaw and Bole, Jour. Amer. Cer. Soc., 5, 311, 1922.
Kallauner, Chem. Ztg., 37, 1317, 1913.
Scherer, Der Magnesit; 1908.
Mitchell, Jour. Chem. Soc. (Eng.), 123, 1055, 1923.
Garnett, Min. Mag., 20, 54, 1923.
- 46.—Knibbs, Lime and Magnesia; page 205.
- 47.—"Magnesite"; Imp. Min. Res. Bur., 1920. (See 104).
- 48.—P. A. Wagner, Magnesite in South Africa; S. Afr. Jour. Ind., Vol. 1, 1918.
Annual Reports, Dept. of Mines, Union of S. Africa.
Rept. Geol. Surv., Transvaal Mines Dept., p. 127, 1906.
- 49.—Summary Report, Geol. Surv. of Can., 1915.
- 50.—Rept., Geol. Surv. of Can., Vol. 11, p. 10, 1898.
- 51.—Middlemiss, Geol. Sur. of India, Vol. 29, p. 31, 1896.
- 52.—H. H. Dains, Jour. Soc. Chem. Ind., 28, 503, 1909.
- 53.—E. Kilburn Scott, Trans. Farad. Soc., Vol. 1, p. 289, 1905.
- 54.—C. H. Burlton, Jour. East. Indian Ass., Vol. 8, p. 1, 1917.
- 55.—Smeeth and Iyengar, Min. Res. of Mysore, Dept. of Min. and Geol., Mysore State Bull. 7, 1916.
- 56.—Ann. Rept., Mines, New South Wales, 1907.
- 57.—Queensland Govt. Min. Jour., Vol. 17, 1916.
- 58.—Review of Min. Oper., South Australia, No. 20, 1914.
- 59.—Rept., Mines Dept., West. Australia, 1915.
- 60.—M. E. Wilson, Magnesite Deposits of Grenville District; Geol. Survey of Canada, Memoir 98, 1917.
- 61.—Rumpf, Tschermak's Min. Mitt., 1873.
- 62.—Redlich, Zeits. f. Prakt. Geol., and Doelter's Handbuch der Min. Chem., Band 1.
- 63.—Cornu, Zeits. f. Prakt. Geol., Vol. 16, 1908.
- 64.—Kern, Gluckauf, Vol. 48, 1912.
- 65.—Horhager, Stahl und Eisen, Vol. 31, 1911.

- 66.—S. J. Cort, Comparison of Open Hearth Furnaces of Various sizes; Amer. Iron & Steel Inst., May 21st, 1926.
- 67.—R. D. Pike, Electric Furnace Refractory; Chem. Met. Eng., 23, 1148.
- 68.—R. H. Youngman, Iron Age, 94, 770,
- 69.—Niinomy, Econ. Geol., Vol. 20, No. 1, 1925.
- 70.—Yoshizawa — Komori, Bull. S. Man. Rly. Co., Dairen, 1919.
- 71.—Davis and Bole, Requirements of Refractories for the Open Hearth; Trans. Amer. Inst. Min. Met. Eng., 1312s, 1924.
- 72.—Smith, Operating Conditions in the Open Hearth as they affect the Life of the Refractory; Jour. Amer. Cer. Soc., Sept., 1923.
- 73.—J. L. Keats and C. H. Herty Jr., The Elimination of Metalloids in the Basic Open Hearth Process; Trans. Amer. Inst. Min. Met. Eng., 73, 1079, 1926.
- 74.—R. M. Keeney, Manufacture of Ferroy-Alloys in Electric Furnaces; Trans. Amer. Inst. Min. Met. Eng., 62, 28, 1920.
- 75.—Eng. Min. Jour. Press, 120, 177, 1925.
- 76.—Backheuer, Stahl und Eisen, 41, 954, 1921.
- 77.—British Clay Worker, 32,174, 1923.
- 78.—Feldtmann, Jour. Amer. Cer. Soc., 2, 1013, 1919.
- 79.—Hartmann and Koehler, Trans. Amer. Elect. Chem. Soc., 37.
- 80.—C. S. Graham, Trans. Amer. Soc., 18, 399, 1919.
- 81.—H. G. Schurecht, Experiments in Dead Burning Dolomite and Magnesite; Jour. Amer. Cer. Soc., Feb., 1921.
- 82.—LeChatelier and Bogitch, Refractory Properties of Silica; Trans. Cer. Soc., 17, 1.
- 83.—Howe, Phelps, and Ferguson, The action of Slag upon Silica, Magnesite, Chrome, Diaspore and Fire Clay Refractories; Jour. Amer. Cer. Soc., 6. (4), 589, 1923.
- 84.—H. Frechette, Canadian Magnesite; Can. Inst. Min. Met., Annual Meeting, 1916.
- 85.—Howe, Phelps, and Ferguson, The effect of Weather upon the Strength of Refractory Brick; Jour. Amer. Cer. Soc., 5, 2, 1922.
- 86.—Howe, A. Study of the Slag Test; Jour. Amer. Cer. Soc., 6, 466, 1923
- 87.—B. M. Larsen, Developments in the Open Hearth Process; Bl. Fur. & St. Pl., Vol. 15, No. 1, Jan., 1927.
- 88.—W. Donald, Magnesia and Magnesia Brick; Engineering, 105, 455, 1918.
- 89.—Norton, The Thermal Expansion of Refractories; Jour. Amer. Cer. Soc.
- 90.—Refractories for Electric Furnaces; Chem. and Met. Eng., Dec. 22nd, 1920.
- 91.—Parravano and Mazzetti, Aurali Chem. Appl., 1923-7, 3-12.
- 92.—Rankin and Merwin, The ternary System —CaO, Al₂O₃, MgO; Jour. Amer. Cer. Soc., 38, 568, 1916.
- 93.—Ruff and Goecke, Z. Angew. Chem., 24, 1459-65.
- 94.—R. B. Sosman, Jour. Ind. Eng. Chem., 8, 985, 1916.
- 95.—W. R. Mott, Amer. Elect. Chem. Soc., Oct. 2nd, 1918.

- 96.—A. T. Green, *Trans. Ceram. Soc. (Eng.)*, 22, 393.
 - 97.—Notes on Magnesite Refractories; *Chem. and Met.*, 21, 704.
 - 98.—R. E. Slade, *Trans. Chem. Soc.*, 93, 327, 1908.
 - 99.—Kowalke and Grenfell, Temperature of Reaction between Graphite and Magnesia; *Trans. Elect. Chem. Soc.*, 27, 221, 1915.
 - 100.—J. A. Hedvall, *Zeits. f. Anorg. Chem.*, 98, 57, 1916.
 - 101.—O. Bischof, On Magnesite Bricks; *Oesterr. Zeits. f. Berg. und Huttenwesen*, 27, 1893.
 - 102.—Hofman and Mostowitsch, *Trans. Amer. Inst. Min. Eng.*, Vol. 39, p. 652.
 - 103.—Campion, E. J., Private communication.
 - 104.—T. Crooks, Magnesite as a Raw Material; *Trans. Cer. Soc.* (1918), Vol. 18, pp. 67-147; said to have been used as a base for the compilation of (47) from which much of the data in connection with deposits in the various countries was obtained.
-

THE CASCADE METHOD OF POURING STEEL

BY J. G. MORROW (*Member, C. Inst. M. & M.*)*

(Toronto, Ont., Meeting, August 26th, 1927)

Many attempts, more or less successful, have been made to increase the yield of sound steel from heats made by open-hearth, electric, or crucible processes. Sound steel in this case was understood to mean metal that was free from pipe and injurious segregation which, when converted into finished product and put to work, gave reliable service. A considerable amount of experimental work, on a commercial scale, was carried out in the open-hearth department of The Steel Company of Canada, at Hamilton, Ontario, under the supervision of Mr. F. B. McKune. Out of these experiments came the 'cascade' method, which consisted of pouring steel from a ladle, through a trough or box, into moulds stepped one below another. These were so connected that the molten metal flowed into and from a box into the highest ingot mould which, after filling, overflowed into the second and third, etc., until the last or lowest ingot mould was filled.

The quality of the usual daily tonnage at this plant was in all respects equal to the best practice in other similar open-hearth works. The scrap used was standard, as was also the pig iron of the charges. Operation of the furnaces was normal and the yield quite consistent with what would be expected from the different types of steel produced. These varied from an open-hearth iron to a spring steel with carbon content of about 1.00 per cent. The cascade method was used only on those heats having a carbon content of 0.30 per cent or higher. This cascade steel, on being bloomed, billeted, and rolled into finished bars, was used for many different purposes, such as automobile forgings, cutlery, springs, wire, etc.

*Metallurgical Engineer, The Steel Company of Canada, Limited, Hamilton, Ontario.

Previous to the use of the cascade method, well known types of brick hot tops had been tried in this work, to increase the yield. These, while partially successful, were at the same time rather costly and did not give as high a yield as ought to be obtained and it was felt that something more could be done to further reduce croppage, and increase the percentage of usable steel. It was decided the most promising field for successful improvement lay in pouring and in controlling the speed of molten steel flowing from the ladle to the ingot moulds, etc. To regulate the stream of metal, a number of devices were tried with little or no success until cascading was worked out step by step and later demonstrated in commercial practice. The steel poured in this manner showed less piping, segregation, etc., and gave higher yields.

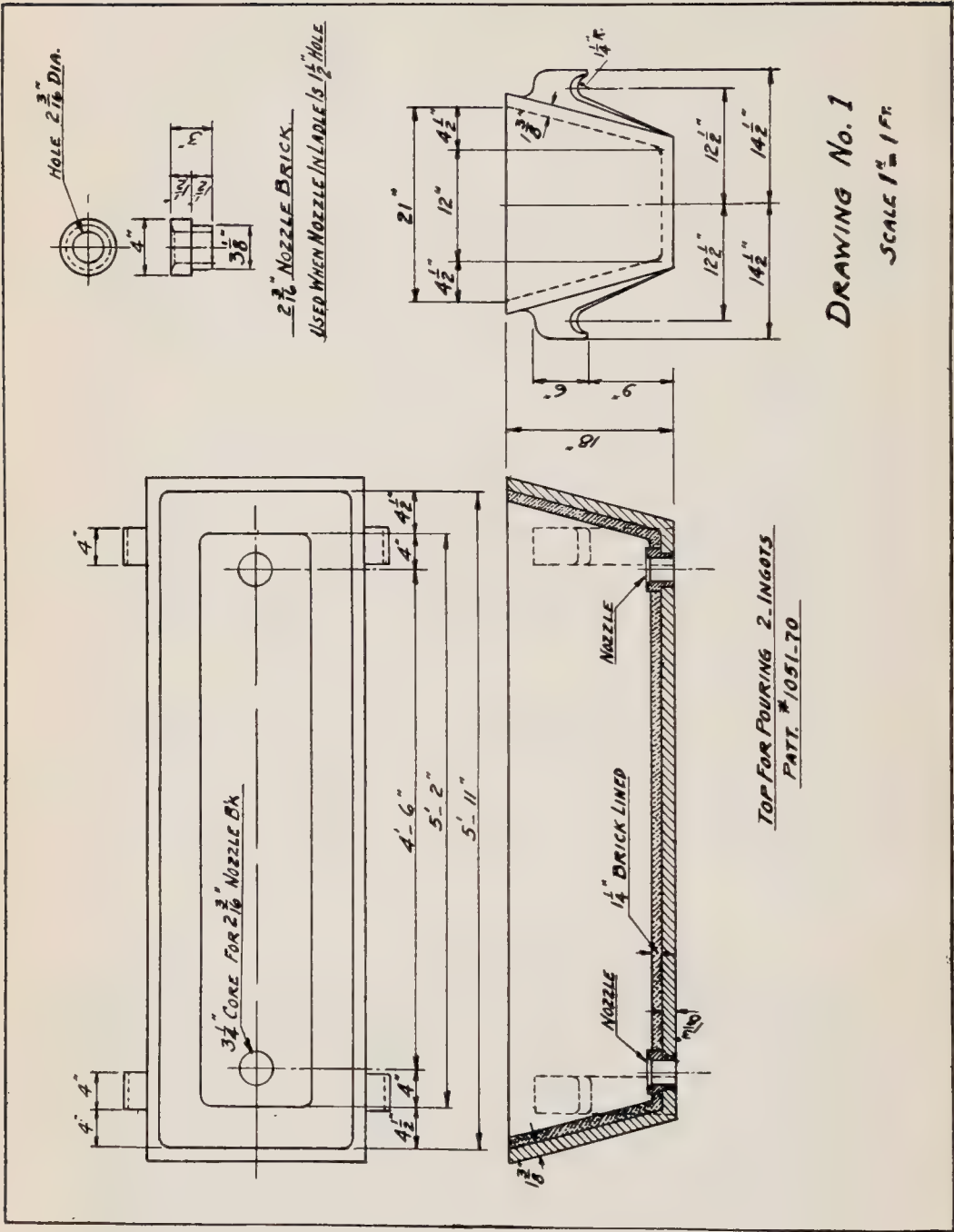
The cascade method as indicated, can be used in most plants without radically changing the equipment either at the open-hearth or in the blooming mill, and set-ups in the former are comparatively simple. The greatest change was in the ingot moulds. These were of ordinary standard type for 6,600-lb. ingot, except that a small spout opening is let in one side of the top and the upper walls are recessed to carry a brick lining.

About twenty years ago, Sauveur and Whiting devised an overflow method of pouring steel in small quantities. These moulds formed three or more top-connected ingots and the inventors affirmed, from their experience, that steel poured in this manner contained less piping. The method, however, was not used to any great extent.

EQUIPMENT

Figure 1 shows the box. It was made of cast iron, about 6 feet in length by 24 inches in width at the top and 15 inches at the bottom. It was lined with bricks and had lugs cast on the sides for easy handling. There were two nozzle holes, one at either end, each hole $2\frac{3}{8}$ inches in diameter. The box rested upon a stand which raised the bottom of the box about 5 inches above the top of the two highest ingot moulds.

The transfer spouts, Figure 2, were 26 inches overall length and approximately 9 inches deep, brick-lined, and cast in iron. The shape and location of the lugs on the side for



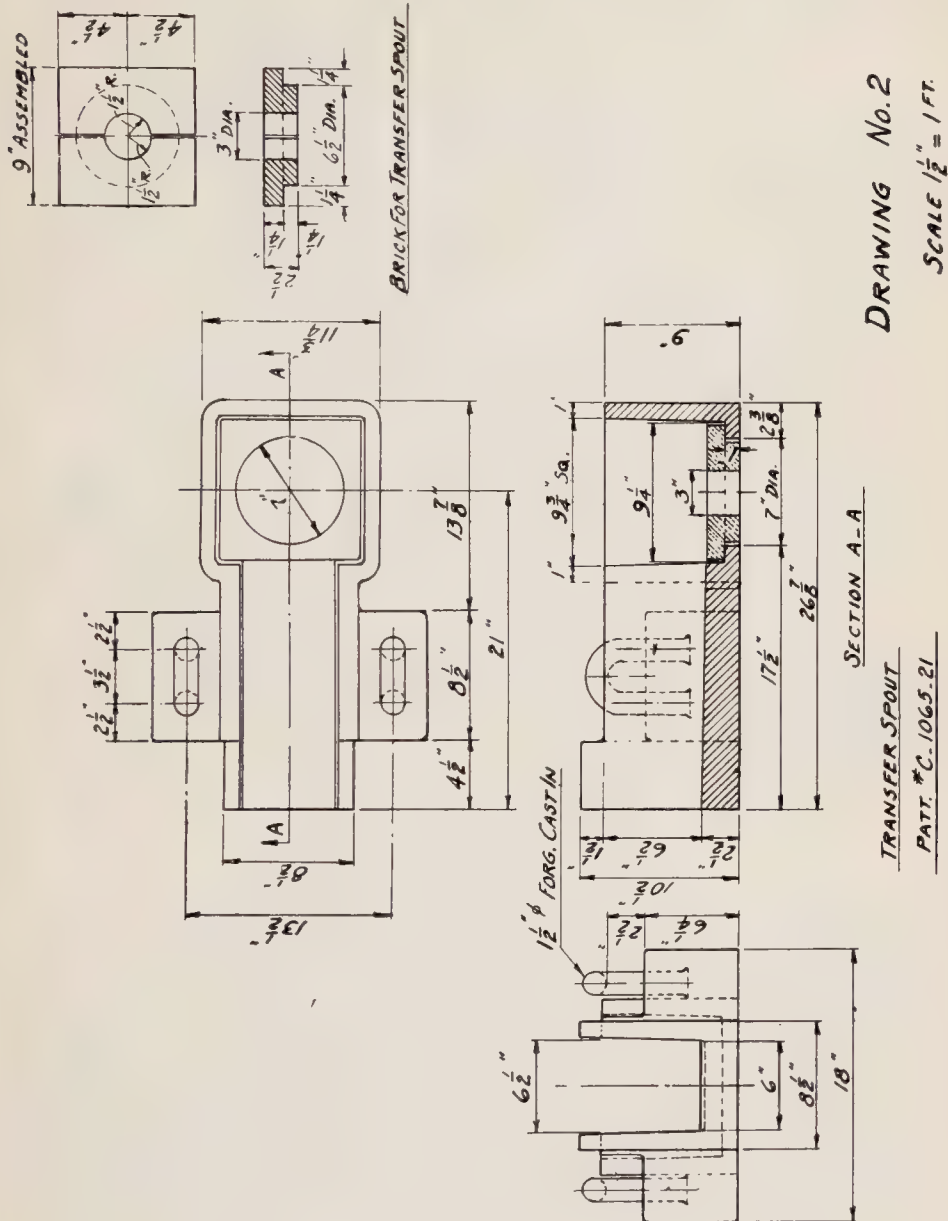


Figure 2.

handling are shown on the drawing. When the spout was in use and suspended over the lower ingot mould, there was located at the upper end a pouring hole 3 inches in diameter. This hole was for centering the stream of metal in filling the lower mould and preventing the splashing of walls, etc.

Ingot moulds were of the ordinary type, size 20 by 20 by 74 inches, such as were used in most works, the only difference being: (1) a slot or opening was let in one side of the mould and, through this opening by way of transfer spout, the molten stream passed from the higher to the lower mould; (2) the upper wall of the mould for a depth of about 13 inches was cast thin, giving a ledge inside of the mould which let in or carried a lining of brick completely around the inside top.

The brick top, as shown in Figure 3, was formed by a number of standard split bricks, 9 by $4\frac{1}{2}$ by $1\frac{1}{4}$ inches, with four corner bricks having a radius of 3 inches to facilitate easy setting up and making for low cost in manufacture.

The stands upon which the ingot moulds were stepped on the cars were of cast iron, as indicated on the assembly drawing (Figure 4), which shows the arrangement of moulds, transfer spouts, and box.

OPERATION

Over a period of about two years no difficulty was experienced in making, for the works, the total requirements of hard steel by the cascade method. The furnace charges were exactly similar to those used previously, and heats were worked in the same manner and time. There was no change in the furnace operations up to the point where the finished heat was in the ladle, although experiments are still being carried on with the object of skimming the major portion of the slag from the metal before it enters the ladle and leaving on it only a blanket of slag about 2 inches deep. By skimming, it is hoped to prevent a considerable quantity of slag becoming mixed or trapped in the liquid steel, from which it is not always able to free itself before solidification.

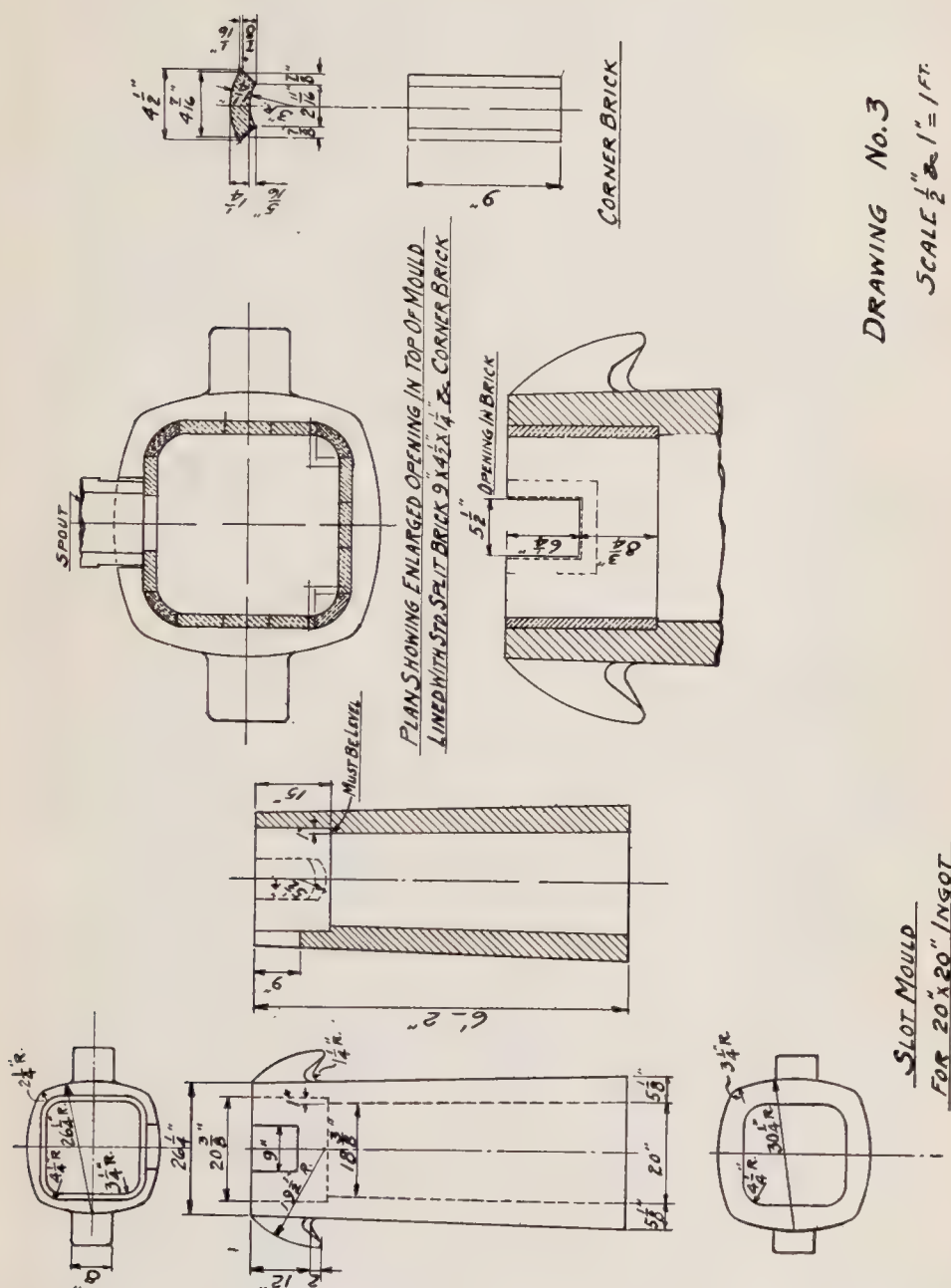
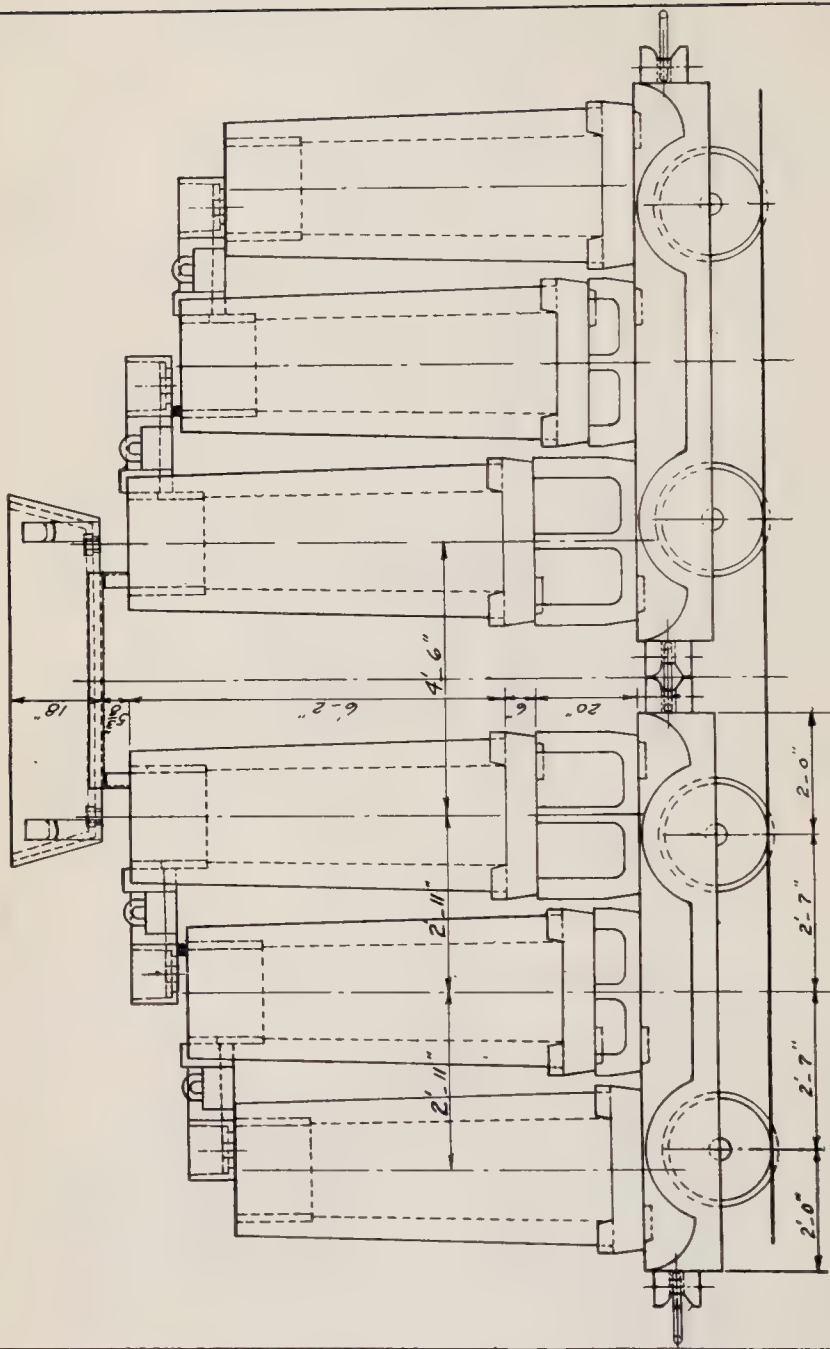


Figure 3.



DRAWING NO. 4

SCALE $\frac{1}{2}$ " = 1 FT.

ARRANGEMENT OF 6 MOULDS FOR POURING
A CONTINUOUS FLOW OF METAL

In pouring a heat of twenty-four ingots by the ordinary method, it is necessary to open and close the ladle stopper twenty-four times, and stopper trouble is not infrequent: cascading required the stopper to be opened only four times to pour the same number of ingots. The advantage was obvious.

There was no extra charge or cost in setting up a stand of moulds or in detaching the connecting troughs after the moulds were filled with steel and in preparation for stripping the ingots for reheating in the blooming mill pits.

Cascading was used daily, demonstrating throughout the period of operation that it was practical and easily worked. The improvement in yield and quality, coupled with the factor of low cost, indicated that the work was justifiable.

RESULTS

It was evident there would be a difference in the yield of sound steel from various ingots in the stand. The topmost ingot poured showed, in most cases, little or no piping; the second contained more than the first, while the lowest had slightly less than regularly poured steel. In order to take advantage of this condition, the method of cropping in common use in blooming mills had to be modified to the extent that each ingot was treated as a unit, and blooms rolled from it were given sufficient cropping to clear them of piping. Another and very close examination was made of the billets on the cooling bed and, where necessary, rejections followed, so that all re-rolled billets were in a sound and satisfactory condition for the purpose for which the steel was later to be used. The yield of sound steel was reckoned on the quantity of billets finally accepted for rolling into finished product. The advantage of materially reducing the amount of proper discard from the top of the ingot at blooming mill shears was due to the fact that the top of each ingot was kept liquid until all metal below had solidified. This was accomplished by cascading the metal from mould to mould as shown in the photograph of the actual operation (Figure 5).

Over a period of several months, in which the general conditions were comparatively similar, the records showed a minimum increase in yield of eleven per cent. This was





Figure 6.—Fractured ingot.

obtained at an increased cost per ton of fifteen cents. It was possible to satisfactorily use the same brick top set-up as often as three or four times. No unusual care or skill was required in setting up this brick top, and this work was satisfactorily done by ordinary pit labour. The ingot, having flush walls throughout its entire length, worked down cleaner in rolling at the blooming mill. The opinion formed from experience in working, as well as from microscopic examination, was that the metal as a whole was cleaner and freer from inclusions than steel poured in the regular manner. A fractured ingot (6,600 lb.) is shown in Figure 6. The upper part has been divided longitudinally and shows the depth of piping, while the lower part shows a transverse fracture, indicating solid metal free from pipe. These fractures were made by first cutting part way through with the oxy-acetylene flame.

Another feature which soon became apparent, was that nearly all ingots seemed to have but few surface defects. This was reflected in the blooms and billets, which required less chipping to put them in a satisfactory condition for finishing. Doubtless this was partly due to the reduced pressure of the metal entering the mould and to the centering of the stream, which prevented splashing of the interior mould walls, etc. The combination of benefits derived from cascading were:

- (1) Increased yield of sound steel.
- (2) Decreased chipping costs.
- (3) A sounder steel containing fewer inclusions, etc.

In order that as much information as possible might be obtained during the work, analyses were made of the gases given off from the top of the ingots after pouring and before solidification. By keeping the top of the metal open in the mould and covering it completely with a suitable dome-like copper cover, it was possible to collect the ascending gases and the average analyses showed the following constituents:

CO ₂	21.8 per cent
CO.....	34.8 "
H.....	35.2 "
N.....	4.8 "

This brief description of the cascade method of pouring steel is given only as a record of the method and the results so far obtained from our work.

THE IMPACT RESISTANCE OF STEELS AT LOW TEMPERATURES†

BY I. F. MORRISON* AND A. E. CAMERON**

(*Member, C. Inst. M. & M.*)

(Jasper, Alta, Meeting, September 19th, 1927)

INTRODUCTION

The need for reliable information on the behaviour of steels when subjected to dynamic stresses at widely differing temperatures has been well set forth by Langenberg⁽¹⁾, who states:

“It is evident that all machinery which is operated in the open in latitudes where there are wide ranges of temperature, such as occur in practically all the Northern States (and Canada) will be called upon to resist severe stresses at those temperatures, and in the case of ordnance, automobiles, tractors, and aeroplanes, such conditions are liable to be exaggerated, since such types of machinery are frequently allowed to remain cold for long periods and then suddenly placed at work, passing quickly from the lowest atmospheric temperature to the highest working temperature. In the case of aeroplanes the machinery may operate at the highest surface atmospheric temperature, and in a very short space of time arrive at altitudes when it will be exposed to temperature lower than any experienced at ground level. A traction engine or tractor, for

†Published with the permission of the National Research Council of Canada.

* Professor of Applied Mechanics, University of Alberta.

** Associate Professor of Mining Engineering, University of Alberta.

(1) “The Behaviour of Certain Steels under Impact at Different Temperatures”, by F. C. Langenberg; Jour. Iron & Steel Inst., Vol. I, 1923.

instance, when cooled by standing idle at an atmospheric temperature of -40°F . (not unusual in certain cold climates), may be started and put to capacity in a very short space of time, the starting subjecting the parts to the severest shocks and impacts”.

The importance of the problem was forcibly brought to the notice of the authors when attention was called to the breakage of street-car axles in the city of Edmonton during the winter months. A circular letter asking for records of the breakages of street-car axles during winter months was sent to several cities in western Canada. The results of this canvass showed conclusively that some definite relation exists between such failures and sub-zero temperatures. Invariably, failures of axles were considerably greater during the winter months than at other times of the year. Careful consideration of the magnitude of the stresses involved, and of the number of reversals of stress during the lives of some of these axles, led to the conclusion that the failures were more probably due to impact than fatigue. More recent information on two breaks which occurred during the last week of December, 1926, has tended to confirm this conclusion.

PREVIOUS WORK

The possible effects of low temperatures upon the physical properties of metals have been recognized by several investigators. Work in the field has been done by such eminent authorities as Sir Robert Hadfield, the late Prof. Kammerlingh Onnes, and the late Sir Edward Dewar. These observers, however, were interested in the possible changes in the physical state of the metal under extremely low temperatures rather than in changes in the mechanical properties. The most complete study of the effects of temperature upon the impact resistance of steels is that made by Langenberg⁽¹⁾. He gave a bibliography of the previous work done on the behaviour of steels

⁽¹⁾ “An Investigation of the Behaviour of Certain Steels under Impact at Different Temperatures”, by F. C. Langenberg; Jour. Iron and Steel Inst., Carnegie Scholarship Memoirs, 1923; also “Investigation of the Influence of Temperature on the Charpy Impact Value of a Group of Steels of Varying Composition”, by F. C. Langenberg; Trans. Amer. Iron & Steel Inst., 1923.

under stress at different temperatures. It contains a list of 12 papers of which 5 were written prior to 1900, *i.e.*, before the recent advances in the science of heat treatment, so that these can be of little more than historic value. Of the remaining seven, the dates of two are not given, but as the list is arranged chronologically they were apparently before 1910; and the remaining 5 are between 1910 and 1922. It is perhaps of interest to note that of these 7 papers, 4 were by French and 3 by German investigators. None of these papers have been available to the authors, and Langenberg makes no comment on them.

Langenberg investigated a series of 18 steels under different conditions of heat treatment and throughout a temperature range of from -80°F. to $1,000^{\circ}\text{F.}$ The steels included low-, medium-, and high-carbon steels, nickel steel, chrome steel, nickel-chrome steel, chrome-vanadium steel, and tungsten steel. The amount of work done was enormous, and Langenberg has carefully and thoughtfully tabulated the actual measurements and represented them graphically. Only a few of his results need be mentioned here. He confirmed the general theory that while the toughness (impact resistance) of all steels increases with increase in temperature, the toughness of many steels may decrease as the temperature falls. He showed that, while this increase in resistance with increase in temperature is not uniform, it reaches a maximum at temperatures ranging from 200°F. to 500°F. The increase in resistance with increase in temperature is rapid within a more or less definite temperature range, this temperature range varying with different steels and for different heat treatments on the same steel. He showed that heat treatment generally has the effect of producing the rapid increase at a lower temperature than that at which it occurs when the steel is in the annealed (or normalized) state; *i.e.*, in the annealed state the rapid increase usually commences at some temperature around 100°F. , and in the heat-treated state the rapid increase occurs at temperatures near or below 0°F.

With regard to the results of the investigations carried out by the authors, Langenberg's results on plain carbon steels at sub-zero temperatures are of prime importance. The carbon content of his steels were: Steel 'G', 0.17 per cent, and Steel 'D', 0.36 per cent. He states:

"At temperatures of zero and lower, there is practically no difference in resistance to impact when these steels are in the annealed condition", and "Comparing steel 'G', the low-carbon steel, in the heat treated condition, with the same steel in the annealed condition, it will be observed that the sudden rise in resistance to impact occurs in the temperature range -80°F. to 0°F. when the material is heat treated, whereas the rise occurred in the range 100° to 200°F. when the steel was in the annealed condition. Similarly the great rise in resistance to impact in the medium-carbon steels occurs in a very much lower temperature range when the steel is heat treated than when the same material is in the annealed condition."

As will be shown later, the first of these conclusions is not borne out by the results of the present investigations. The second result indicates that the heat treatment applied is decidedly beneficial in increasing impact resistance at low temperature, but it does not give quantitative results on what particular heat treatment is most beneficial. Langenberg made a more detailed study of another medium-carbon steel (his steel 'M'), but his results are shown for only duplicate specimens and in a number of cases for only one specimen, and, therefore, cannot be taken as a very reliable guide.

Recently R. Yamada has reported on the results of impact tests of steels at low temperatures⁽¹⁾. His investigations covered bending and tension, and repeated the Charpy impact tests on plain carbon, nickel, chromium, and nickel-chromium steels under different heat treatments, and throughout a temperature range of from $+22^{\circ}\text{C.}$ to -190°C. For his bending impact tests, Yamada used a round piece with 45° notch and of varying depth. He summarizes the results of his investigations as follows:

1. "For the investigation of the brittleness of steels, the single bending and tension impact test and the repeated impact test were made. The materials tested were plain carbon and alloy steels with pearlitic and sorbitic structures.

(1) "On the Impact Test of Steels at Low Temperatures," by Ryonosuke Yamada; Science Reports of the Tohoku Imperial University, Series I, Vol. XV, No. 5, November, 1926.

2. "The brittleness of steels increased generally with the fall of temperature, and steels with a sorbitic structure are much tougher than those with a pearlitic structure at all temperatures.
3. "Tested in an annealed condition, steels alloyed with nickel and chromium are, in general, tougher than plain carbon steels, and the increase in brittleness with the fall of temperature is comparatively slight.
3. "The absorbed energy-temperature curve and the bending angle-temperature curve are exactly similar, and hence the relation between the absorbed energy and the bending angle is represented by a straight line, which almost passes through the origin; that is, the energy spent, apart from that of the bending or deformation, is very small in amount.
5. "The surface of fracture in some test-pieces broken by impact was examined microscopically. In the case of ferrite the fracture is intracrystalline at ordinary temperatures, and, with increasing brittleness, the intercrystalline fracture takes place to some degree. Pearlite is broken in all directions, independent of the direction of the lamellar".

Yamada's work is of importance in determining the relative effects of low temperatures upon the impact resistance of steels. In general his results on plain carbon steel conform to those reported by the present authors. It is to be regretted that he did not use the established Charpy impact specimen in order that a more definite comparison could be made.

THE PRESENT INVESTIGATION

This investigation was made possible by a grant received from the National Research Council of Canada, and has been carried out by the authors at the Engineering Laboratories of the University of Alberta. The impact machine was purchased in France and is of the genuine Charpy type. The Charpy type was selected as being suitable for the quick operation necessary in breaking the specimens. Also, Langenberg's work was carried out with this type of machine, and it seemed desirable to use a similar type for purposes of comparison.

The characteristics of the machine used are given by the following constants: Wt. of pendulum, 22,665 kg.; radius to c.g. of pendulum, 696.5 mm.; capacity, 30 kg.m.

The remaining apparatus necessary in the conduct of the work was designed and made under the direction of the authors at the University of Alberta.

The steel was supplied as one-half-inch square bars, free of cost, by the U.S. Steel Products Co., Ltd., of Winnipeg, direct from the rolling mills to the University. The company very kindly also supplied the heat numbers and the ladle analyses of the steels. The authors wish to acknowledge the kindness of the U.S. Steel Products Co. in supplying this material. Also they wish to acknowledge the occasional assistance of Mr. H. R. Webb, of the Department of Civil Engineering, and of the two senior students who helped in carrying out the tests.

STEELS INVESTIGATED

For the purpose of the investigation, two carbon steels were selected which would represent standard material used for machinery and structural purposes under conditions where it is likely to be subjected to sub-zero temperatures. Ladle analyses of the steels studied are shown in Table I.

Table I.—Ladle analyses of steels

Steel	C Per cent	Mn Per cent	P Per cent	S Per cent
'A'	0.10	0.42	0.015	0.044
'B'	0.34	0.60	0.014	0.042

Steel 'A' would meet the standard specifications for structural steel for locomotives (A.S.T.M. serial A 10-21), or structural steel for cars (A.S.T.M. serial 11-21).

Steel 'B' was intended to represent a typical carbon steel for car axles, but would scarcely meet the standard specifications for such material (A.S.T.M. serial A 21-18).

PREPARATION OF CHARPY SPECIMENS

The standard Charpy specimens, 0.394 in. by 0.394 in. by 2.2 in. were prepared as follows: The one-half-inch square bar was cut to length and the pieces first given a preliminary

anneal by heating in an electric muffle furnace to the normalizing temperature and held at that temperature for half an hour. The steels were air-cooled from this treatment. By the use of a specially constructed jig, the specimens were brought nearly to size by means of a lathe and were subsequently brought to the standard dimensions on a grinding belt, care being taken to eliminate all the lathe tool marks. The notch hole, 0.055 in. diam., was then drilled 0.225 in. from one face, and also a hole at one end for suspension in the heat treatment furnace. The specimens were next given the heat treatment in batches of 8 or 12, the temperature of each batch being carefully controlled. On completion of the heat treatment the notch was completed with a saw cut, care being taken to prevent the saw scratching the rounded bottom of the notch. On the completion of the preparation of the specimens, they were arranged in ventilated wooden trays. Each tray carried 5 rows of four specimens each, *i.e.*, 20 specimens in all. Each row represented a definite heat treatment.

HEAT TREATMENT

The purposes of the investigation were twofold: (a) to determine changes in Charpy impact values with changes in temperature; and (b) to determine what heat treatment is best adapted for steel to resist shock at low atmospheric temperatures. For these purposes the standard Charpy impact specimens were prepared and subjected to heat treatments as shown in Table II.

Table II.—Heat Treatment

Heat treatment No:—	1	2		3		4		5
Heat treatment:	Quenching	Quench	Draw	Quench	Draw	Quench	Draw	Normalize
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Steel 'A'.....	1,650	1,650	440	1,650	810	1,650	1,175	1,650
Steel 'B'.....	1,575	1,575	440	1,575	810	1,575	1,175	1,575

All specimens except the normalized were quenched in water at 70°F., and those which were drawn were quenched in water at 70°F., from the drawing temperature.

ATMOSPHERIC TEMPERATURES

It was planned to subject the steels to the following temperatures: +10°F., 0°F., -10°F., -20°F., -30°F., and -40°F., as these temperatures are usually obtainable during the winter months at Edmonton. For purposes of comparison, one complete set of specimens was also to be broken at room temperature (70°F.).

It was realized that there would be a considerable temperature change during the period of placing the specimens in the machine. To obtain a measure of this, the Charpy impact machine was placed as close to the main door of the laboratory as possible, and the time required to remove a specimen from a tray, carry it into the laboratory, place it in the machine and break it, was determined. An average of several observations showed an interval of less than 6 seconds for these operations. To obtain the rate of temperature rise of the metal, a dummy specimen was prepared to hold the bulb of an alcohol thermometer graduated to one-fifth of a degree. This specimen, with the thermometer inserted, was exposed to atmospheric temperature with the specimens. To minimize these temperature changes the specimens were all given a thin coat of paraffin wax.

EXPERIMENTAL RESULTS

Weather conditions during the winter of 1926-27 did not permit of the complete carrying out of the investigation as planned, the lowest temperature obtained being about -30°F. The results obtained, however, were sufficient to show clearly the nature of the effects of low atmospheric temperatures upon the impact resistance of the steels in question.

The results of the investigations are shown in tabular form in Tables III and IV. In the majority of cases these results are the average of 4 determinations, and in no case is the average based on less than 3 determinations.

HEAT TREATMENT — EXPERIMENTAL RESULTS
Table III.—Charpy impact tests on steel 'A' (Carbon 0.10 per cent)

Quenched at 1,650°F.		Quenched at 1,650°F. Drawn at 440°F.		Quenched at 1,650°F. Drawn at 810°F.		Quenched at 1,650°F. Drawn at 1,175°F.		Normalized at 1,650°F.	
Temp. of test, °F.	Charpy value, ft. lb. per std. spec.	Temp. of test, °F.	Charpy value, ft. lb. per std. spec.	Temp. of test, °F.	Charpy value, ft. lb. per std. spec.	Temp. of test, °F.	Charpy value, ft. lb. per std. spec.	Temp. of test, °F.	Charpy value, ft. lb. per std. spec.
+68	49.5	+68	54.0	+68	61.5	+68	67.0	+68	67.0
+12	52.5	+12	57.5	+12	59.5	+12	69.5	+12	51.5
-3	43.0	-3	52.0	-2	55.0	-2	61.5	-2	50.5
-10	43.5	-10	50.5	-10	50.5	-10	60.5	-10	19.0
-18	44.5	-18	58.5	-18	58.5	-18	62.5	-18	6.0
-22	49.5	-22	58.5	-23	58.5	-23	64.0	-22	6.0

Table IV.—Charpy impact tests on steel 'B' (Carbon 0.34 per cent)

Quenched at 1,575°F.		Quenched at 1,575°F. Drawn at 440°F.		Quenched at 1,575°F. Drawn at 810°F.		Quenched at 1,575°F. Drawn at 1,175°F.		Normalized at 1,575°F.	
Temp. of test, °F.	Charpy value, ft. lb. per std. spec.	Temp. of test, °F.	Charpy value, ft. lb. per std. spec.	Temp. of test, °F.	Charpy value, ft. lb. per std. spec.	Temp. of test, °F.	Charpy value, ft. lb. per std. spec.	Temp. of test, °F.	Charpy value, ft. lb. per std. spec.
+68	26.5	+68	16.5	+68	30.0	+68	42.0	+68	29.0
+12	11.0	+12	14.0	+12	25.5	+12	31.5	+12	20.7
-4	10.5	-4	12.5	-4	24.0	-4	26.5	-3	18.0
-10	8.0	-10	14.0	-10	22.0	-10	27.0	-10	17.5
-18	12.0	-18	9.5	-18	21.5	-18	26.0	-18	8.0
-25	15.0	-25	9.5	-26	21.0	-26	31.0	-24	9.0

DISCUSSION OF RESULTS

The results tabulated in Tables III and IV present many points of interest, only a few of which will be discussed.

Perhaps the most striking result is the influence of heat treatment of a low-carbon steel (steel 'A') on the impact resistance at low temperatures. This steel, with a carbon content of 0.10 per cent, represents a very large class of steels used in the hot-worked condition, but seldom, except as the core of case-hardened articles, given a heat treatment. The microstructure of the normalized steel may be taken as equivalent to that of the steel in the hot worked condition, and the results of the investigations clearly show that a normalized steel of this composition rapidly loses its resistance to impact at temperatures below zero degrees fahrenheit. For example, at -22°F. the impact resistance of the steel was only one-tenth of that which it had at room temperature. If heat treated, however, the impact resistance of the steel is not materially affected by temperatures as low as those reached in the experiments, and if the steel is quenched and fully drawn, the impact resistance at -20°F. is practically the same as that of the normalized steel at room temperature.

The character of the fractures produced in the normalized steel is shown in Figure 1. It is to be noted that the fracture varies remarkably with the atmospheric temperature. At room temperature, the fracture is the silky fibrous type characteristic of a low-carbon steel. At lower temperature the fracture tends to become crystalline at the centre, and the relative amount of the crystalline area increases as the temperature decreases until, at -10°F. , the whole of the fracture is crystalline. It is not likely that the microstructure of the metal changes in a similar manner. Figure 4 shows the microstructure of a specimen of normalized steel 'A' which was tested at -26°F. , but subsequently prepared for microscopic examination at room temperature. This structure is identical with the structure of a normalized low-carbon steel at room temperature, and it is not likely that changes in structure would be reversible. Pearlite areas are small and well segregated; and the resistance to fracture must be mainly

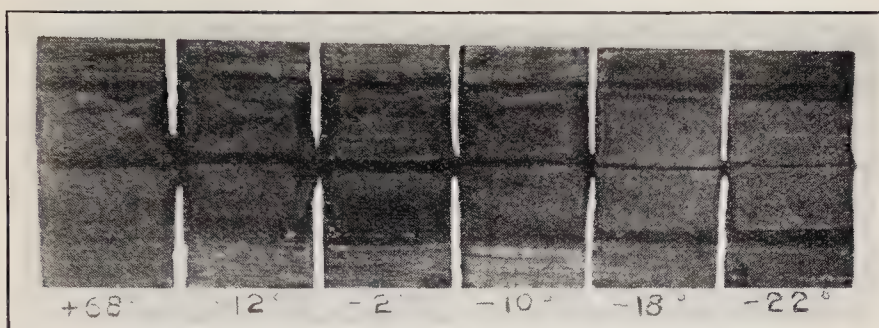


Figure 1.—Fractures in steel 'A' (0.10 per cent C) normalized at 1,650°F.

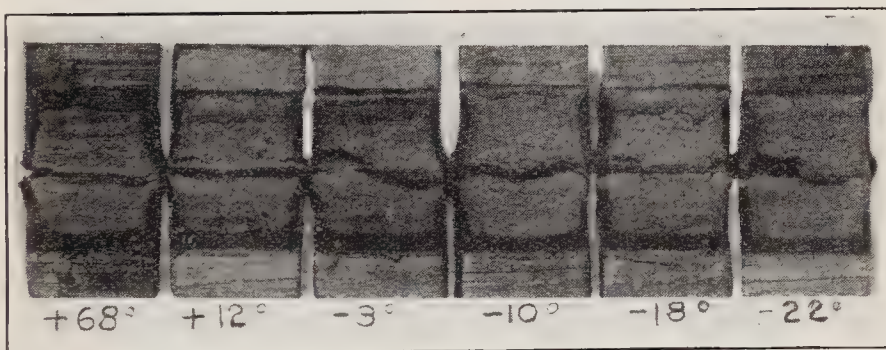


Figure 2.—Fractures in steel 'A' (0.10 per cent C) quenched from 1,650°F., drawn at 440°F.

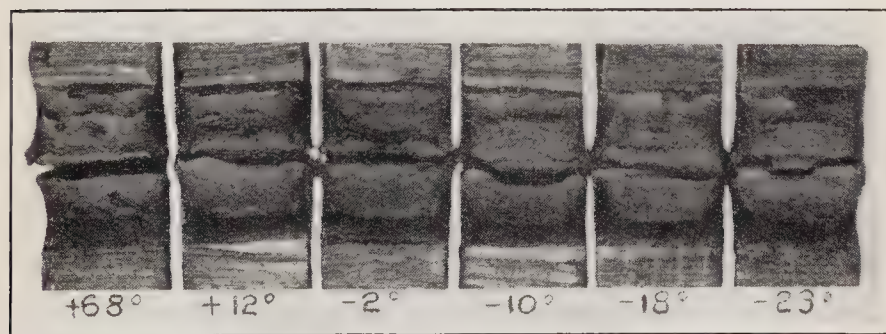


Figure 3.—Fractures in steel 'A' (0.10 per cent C) quenched from 1,650°F., drawn at 1,175°F.

that of the polyhedral ferrite crystals. The low-temperature brittleness of this steel in the normalized condition, therefore, appears to be due to low-temperature brittleness of ferrite.

The character of the fracture produced in steel 'A' when quenched and drawn at 440°F., is shown in Figure 2, and those produced in the steel when quenched and fully drawn (drawn at 1,175°F.) in Figure 3. It is to be noted that the type of fracture in these cases is wholly fibrous and silky, and there is no variation with change in atmospheric temperature. The corresponding microstructures of the specimens broken at -18°F. are shown in Figures 5 and 6. Figure 5 shows the acicular structure of low-carbon martensite, which, according to Hanne-man and Schrader⁽¹⁾, is an intergrowth of 'epsilon' and 'eta' crystals. The absence of any troostite is of particular interest. In Figure 6 the acicular structure is still pronouncedly evident, although the individual needles are coarser. The structure is sorbitic in that cementite has precipitated from the 'eta' phase, and the dispersion of the cementite, together with the acicular structure, is undoubtedly responsible for the permanence of toughness at low temperature.

The results of the investigations on steel 'B' (0.34 per cent C) are, in general, analogous to those obtained on steel 'A'. For example, it is clearly shown that the impact resistance of the normalized steel is much less at sub-zero temperatures than at room temperatures. A steel of this carbon content is normally more brittle at room temperatures than a steel of lower carbon content. Hence the proportional loss in impact resistance is not as great as in the previous case. It is important to note that the impact resistance of steel 'B' in the normalized condition never fell to as low a figure as that recorded for steel 'A'. This is contrary to Langenberg's findings as quoted previously.

The character of the fractures obtained with steel 'B' in the normalized state for the 6 different temperatures of testing are shown in Figure 7. At room temperature the fracture was part fibrous and part crystalline. At lower temperatures the relative proportion of these two types changes, the fibrous outer area decreasing and the crystalline area increasing

(1) Trans. A.S.S.T., February, 1926, p. 169.

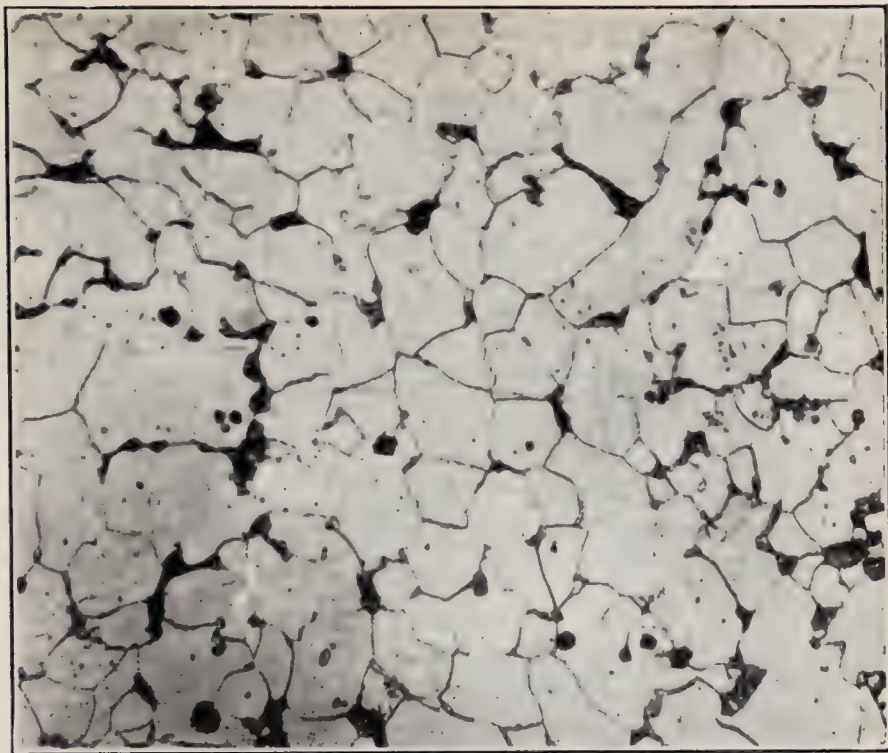


Figure 4.—Microstructure of steel 'A' (0.10 per cent C) normalized at 1,650°F. ($\times 375$)

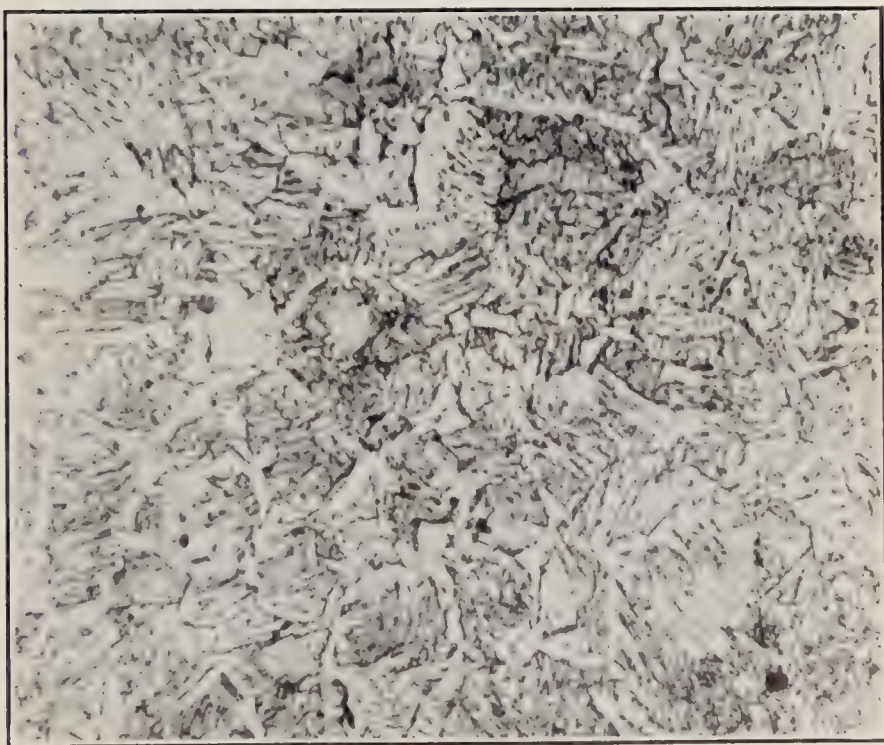


Figure 5.—Microstructure of steel 'A' (0.10 per cent C) quenched from 1,650°F., drawn at 440°F. ($\times 375$)

until, at -18°F. , the fibrous structure has wholly disappeared and the fracture is identical with that of the normalized low-carbon steel at the same temperature. The microstructure of a typical specimen broken at -18°F. is shown in Figure 10. Here again the crystalline fracture appears to be due to low-temperature brittleness of the ferrite crystals.

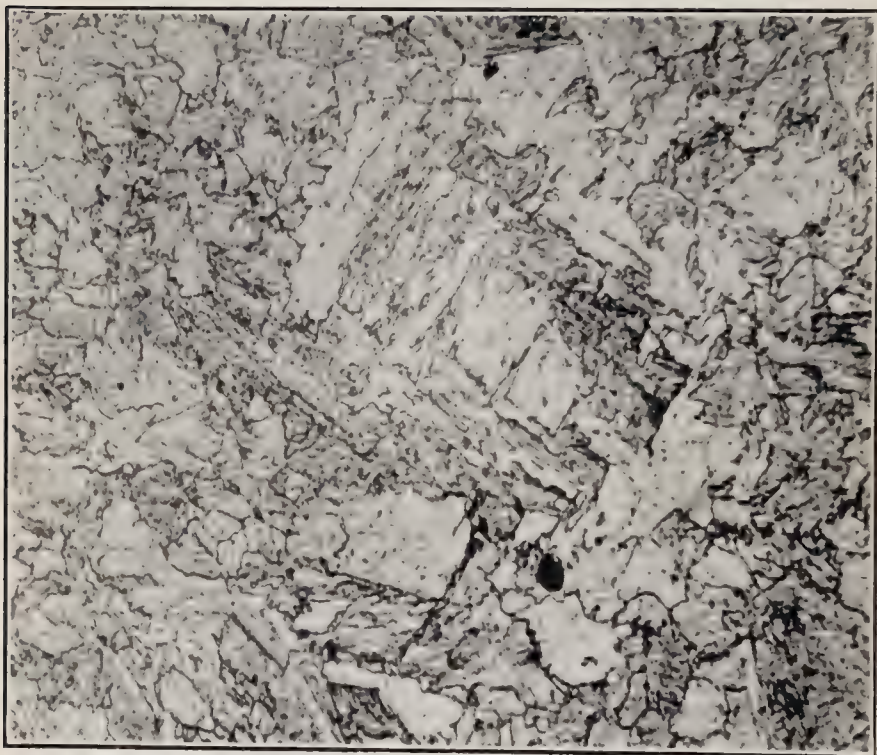


Figure 6.—Microstructure of steel 'A' (0.10 per cent C) quenched from $1,650^{\circ}\text{F.}$, drawn at $1,175^{\circ}\text{F.}$ ($\times 375$)

The character of the fracture produced in steel 'B' when quenched and drawn at 440°F. is shown in Figure 8. There is very little change from the fracture produced in the normalized steel, and this is in accordance with the results tabulated in Table IV. The microstructure of a typical specimen, broken at -18°F. , is shown in Figure 11. It is a troostite-austenite structure, the most pronounced feature being the polyhedral character of the grains. Apparently the globular or polyhedral grains of troostite and austenite are as brittle at low temperatures as are the polyhedral grains of ferrite.

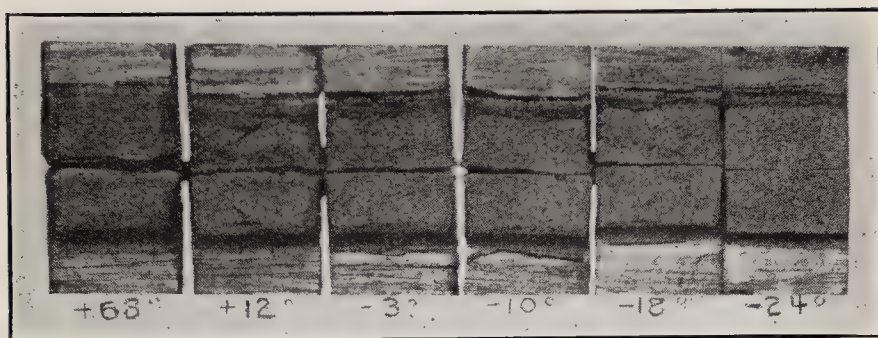


Figure 7.—Fractures in steel 'B' (0.34 per cent C)
normalized at 1,575°F.

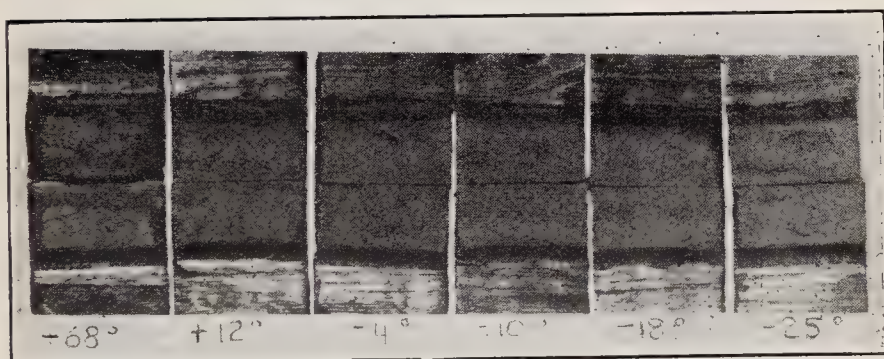


Figure 8.—Fractures in steel 'B' (0.34 per cent C)
quenched from 1,575°F., drawn at 440°F.

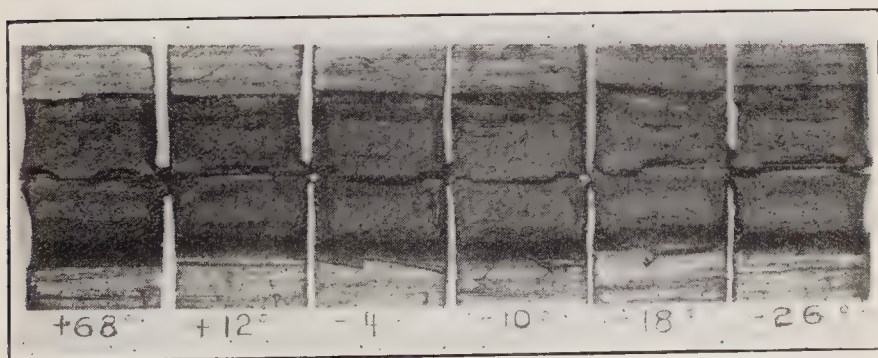


Figure 9.—Fractures in steel 'B' (0.34 per cent C)
quenched from 1,575°F., drawn at 1,175°F.

The fractures obtained in steel 'B' when quenched and fully drawn (drawn at 1,175°F.) are shown in Figure 9. They show a part fibrous, part crystalline surface similar to the fracture of the normalized steel at room temperature. It is to be noted, however, that there is only a slight change in the relative amounts of the two types with lowering temperature. The microstructure of a typical specimen broken at -18°F. is shown in Figure 12. It shows a general sorbitic character, but the acicular structure is again in evidence, although there are some polyhedral grains of ferrite present. Cementite is well dispersed, and this dispersion of the cementite, together with the acicular structure, is probably responsible for the increased resistance to impact at low temperature.

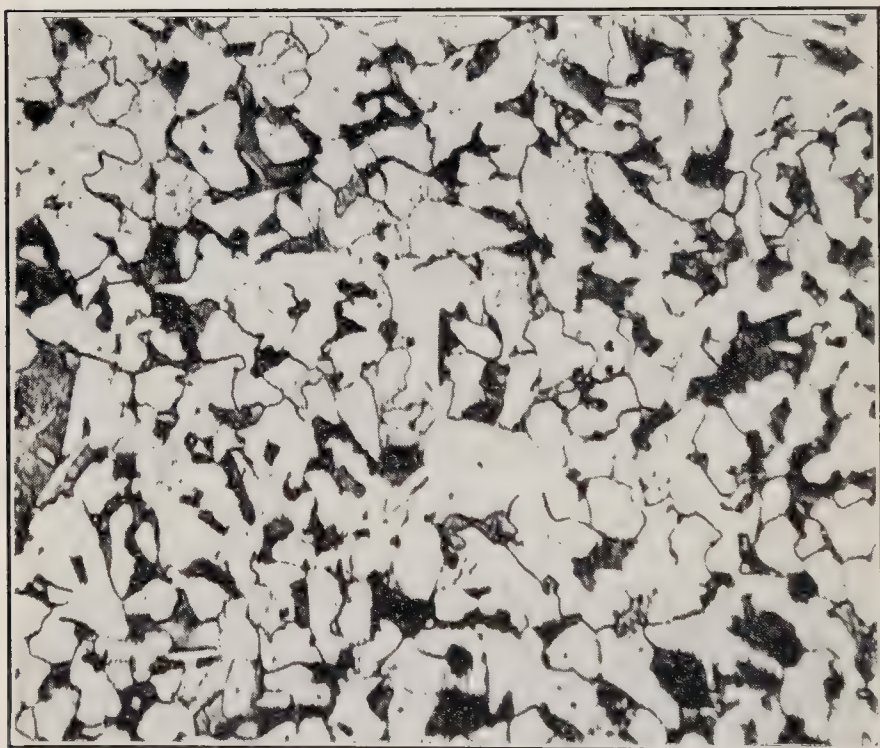


Figure 10.—Microstructure of steel 'B' (0.34 per cent C) normalized at 1,575°F. ($\times 375$)

From the above observations, it appears to the authors that one prime source of low-temperature brittleness is a polyhedral structure. The coarse polyhedral structures have in



Figure 11.—Microstructure of steel 'B' (0.34 per cent C) quenched from 1,575°F., drawn at 440°F. ($\times 375$)

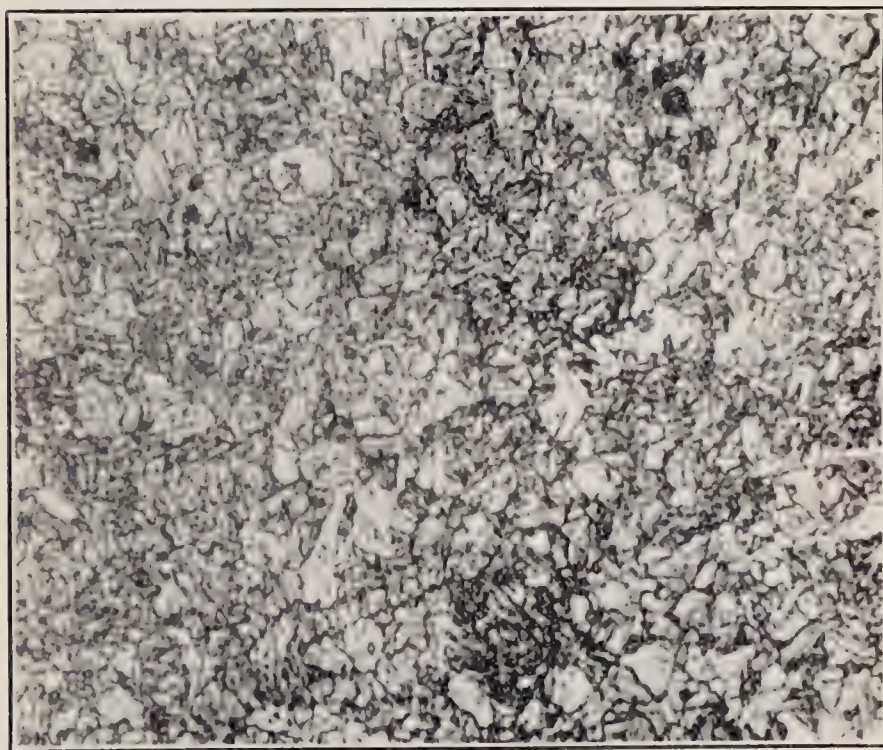


Figure 12.—Microstructure of steel 'B' (0.34 per cent C) quenched from 1,575°F., drawn at 1,175°F. ($\times 375$)

all cases shown a low impact value at low atmospheric temperatures, while an acicular structure, as in the heat-treated low-carbon steel, and the finely divided sorbitic structure of the medium-carbon steel, show practically no change in impact value, due to low atmospheric temperature. Presumably the acicular structure may itself be brittle, as in the case of a high-carbon martensite, but this structure should show little, if any, change in impact value with lower temperatures.

CONCLUSIONS

From the results of the investigations the following practical conclusions have been drawn:

1. Low temperatures, in all cases, lower the impact resistance of low- and medium-carbon steels.
2. In the normalized condition, the impact resistance of low- and medium-carbon steels is markedly decreased for temperatures below 0°F . At -20°F . the impact resistance of low-carbon steel is less than one-tenth, and of medium-carbon less than one-third, the resistance of these steels at room temperatures. Obviously steel in this condition is in the most unsuitable condition to withstand shock at temperatures below 0°F .
3. Any heat treatment, other than normalizing or annealing, is preferable where a low- or medium-carbon steel is to be subjected to shock when under the influence of temperatures at least as low as -25°F . Although the impact resistance of these steels at any heat treatment is reduced, due to the low temperature, the reduction is only a fraction of that occurring when the steel is in the normalized condition.
4. Plain carbon steels in a quenched and fully drawn condition offer greater resistance to impact at low temperatures than for any other heat treatment.
5. In the case of plain carbon steels that are likely to be subjected to shock at temperatures below zero degrees fahrenheit, for best service it is necessary to give the steel some heat

treatment other than annealing or normalizing. In general, the authors would recommend proper quenching followed by drawing at temperatures around 1,100°F.

6. In the case of street-car axles for use in cities in northern latitudes, it seems advisable to recommend that they be purchased with a specified heat treatment, as outlined above. The general practice of annealing axles after a period of service is detrimental from the point of view of resistance to impact. From the investigations, the authors feel that this practice may account for some of the failures during cold weather.

SMELTING TITANIFEROUS ORES OF IRON

BY ALFRED STANSFIELD (*Member, C. Inst. M. & M.*)*

(Montreal, Que., Meeting, August 23rd, 1927)

INTRODUCTION

About seventy years ago, when iron was still being smelted to a large extent in small charcoal blast-furnaces, titaniferous ores were used commercially for the production of pig iron and no serious difficulty was encountered in smelting them, though the consumption of fuel was higher than with other ores. When charcoal was largely replaced by coke in the blast-furnace, serious trouble was experienced in smelting titaniferous ores and such ores are no longer employed in the iron industry.

For many years there was no exact knowledge on this subject, but the iron smelters were strongly prejudiced against titaniferous ores. During the last twenty years or so experiments have been carried out on a large scale and in the laboratory, but the literature is still decidedly contradictory. The writer has been interested in this subject for a number of years and has directed many laboratory experiments, which are now beginning to explain the situation. These experiments are still very far from being complete, but are sufficiently advanced to make it worth while to place the subject before the Congress for consideration.

This paper contains a brief survey of the published information, bringing out some points that have been overlooked by other writers, and shows how the conflicting opinions of these writers can be reconciled in view of recent experiments. The paper also indicates the direction in which further informa-

*Professor of Metallurgy, McGill University, Montreal.

tion should be sought. The smelting of titaniferous ores may not be of immediate commercial importance, but, in view of the large deposits of titaniferous magnetites in Canada, it is a subject that should be studied in preparation for future developments.

Iron smelting in Canada is in an anomalous position, as the iron ore and a large proportion of the fuel is imported from other countries. As regards the ore, the situation is as follows:

Canadian Iron-Smelting in 1926

Pig iron produced in Ontario.....	488,000 tons
“ “ “ “ Nova Scotia.....	250,000 “
“ “ “ “ Canada.....	738,000 “
Iron ore from U.S. imported to Ontario.....	847,000 “
Iron ore from Newfoundland imported to Nova Scotia	466,000 “
Iron ore imported to Canada.....	1,313,000 “
Canadian ore smelted.....	None

Even if we regard Newfoundland ore as, in a sense, domestic, it will be seen that a large proportion of the iron ore that is smelted in Canadian furnaces is of foreign origin, being derived from the Lake Superior deposits located in the United States.

Canadian deposits of iron ore are in general less amenable to blast-furnace smelting than the United States ores and cannot at present compete commercially with the imported ores. Sooner or later, however, as the United States mines become exhausted, Canadian ores will be used in Canadian furnaces. This will result partly from the depletion of the Lake Superior deposits, partly perhaps from discoveries of Canadian ores such as those in Hudson bay, and partly from improvements in ore preparation and smelting methods that will permit the Canadian ores that are at present available, to be used in competition with imported ores. At present the Lake Superior ores, which are easily smelted, can be imported so cheaply that there is no margin left to cover the cost of preparing the Canadian ores, but as the Lake ores become less abundant beneficiation of Canadian ores will become possible.

Some of the important deposits of iron ore in Canada are titaniferous, and as it is probable that some of these ores will

be smelted sooner or later, it is desirable to collect information and carry out experiments to find precisely what can be accomplished with such ores.

CANADIAN DEPOSITS

The occurrences of titaniferous iron ores in Canada are described by A. H. A. Robinson ⁽¹⁾. Four important deposits of titaniferous magnetites which may be mentioned, are on the Saguenay river near lake St. John, Quebec; at the bay of Seven Islands on the north shore of the lower St. Lawrence; on the shores of Seine bay and Bad Vermilion lake in western Ontario; and in the foothills of the Rocky mountains near Burmis, Alberta. These deposits are all large enough to receive consideration as possible sources of iron ore, though no estimate is made of the tonnage available. The report of each may be summarized as follows:

1. *St. Charles Prospect:*

This is on the Saguenay river near lake St. John. The ore outcrops over an area of about 700 ft. by 200 ft. Samples show 50-52 per cent of iron, 10 to 13 per cent of titanium, 0.05 to 0.08 per cent of phosphorus, and 0.03 to 0.5 per cent of sulphur. Magnetic concentration yields a concentrate with 56 per cent of iron and 8 per cent of titanium.

2. *Bay of Seven Islands:*

This is on the north shore of the lower St. Lawrence, 340 miles below Quebec city. There are a number of small deposits in this district, some of which have been mined for iron ore. Analyses vary widely, but samples of titaniferous magnetite show 40 to 58 per cent of iron, 9 to 16 per cent of titanium, 0.02 to 0.2 per cent of phosphorus, and 0.07 to 0.6 per cent of sulphur. Magnetic concentration of an ore containing 41 per cent of iron and 16 per cent of titanium yielded a concentrate with 55 per cent of iron and 12 per cent of titanium.

3. *Rainy River District:*

The most extensive deposits of titaniferous magnetites known in Canada extend for 14 miles along the north shores of Bad Vermilion lake and Seine bay of Rainy lake, in the

⁽¹⁾ A. H. A. Robinson, "Titanium". Report No. 579, Mines Branch, Department of Mines, Ottawa, 1922.

Rainy River district of western Ontario. The outcrops, in places, are 20 or 30 feet wide. Samples taken for analysis contained from 30 to 50 per cent of iron, 6 to 16 per cent of titanium, 0.02 to 1.4 per cent of phosphorus and 0.04 to 0.3 per cent of sulphur. Magnetic treatment of a sample containing 46 per cent of iron and 17 per cent of titanium give a concentrate with 50 per cent of iron and 15 per cent of titanium.

4. *Burmis, Alberta:*

Beds of consolidated titaniferous magnetite sand, which may be valuable as ores of iron, occur at Burmis, a station on the Crowsnest Pass division of the Canadian Pacific railway, nine miles east of the coal-mining town of Blairmore. Analyses show 40 to 59 per cent of iron, 2 to 4 per cent of titanium, nothing to 0.4 per cent of phosphorus, and trace to 0.06 per cent of sulphur.

NATURE OF THE ORES

Titanium occurs in nature as the dioxide, TiO_2 , forming most commonly the mineral rutile. It occurs in combination with iron as ilmenite or titanite, which is usually regarded as $\text{FeO} \cdot \text{TiO}_2$, but which varies widely in composition through addition of either Fe_2O_3 or TiO_2 , from a slightly titaniferous hematite to a nearly pure rutile.

Titaniferous iron ore is usually an intimate mixture of magnetite and ilmenite. Ore containing from 18 to 24 per cent of titanium is termed ilmenite, while magnetite ore with 2 to 15 per cent of titanium is known as titaniferous magnetite. Ore with less than 2 per cent of titanium (3 per cent of TiO_2) is usually classed with ordinary iron ore, as it is supposed that this amount of titanium will not interfere with its use in the blast furnace (').

MAGNETIC CONCENTRATION

As ilmenite is only slightly magnetic, it would be expected that titaniferous magnetites, when crushed, could be treated magnetically so as to yield a concentrate rich in iron and

(1) W. M. Bowron, "The practical metallurgy of titaniferous ores", Trans. Am. Inst. Min. Eng. 1882, Vol. 11, p. 159. P. E. Dulieux, "Les Minerais de Fer de la Province de Québec", Service des Mines, Québec, 1915, p. 15; also "Preliminary Report on some Iron Ore deposits in the Province of Quebec", Mines Branch, Québec, 1913, p. 75.

nearly free from titanium, and at the same time to give an ilmenite product that could be used for the manufacture of titanium paint and ferro-titanium. The iron and the titanium are, however, so intimately associated in most of these ores that it is impossible to obtain a satisfactory separation. Most of the Canadian ores that have been tested give magnetic concentrates with 45 to 55 per cent of iron and 8 to 15 per cent of titanium. In order to obtain even this degree of concentration, the ore must be crushed rather finely and the concentrate would need to be sintered or briquetted before it could be used in the blast-furnace.

OLD SMELTING PRACTICE

Three typical examples may be mentioned:

For more than a hundred years, iron ores containing 6 or 7 per cent of titanic acid have been smelted with charcoal in small blast-furnaces at Taberg in Sweden ⁽¹⁾. As late as 1875 ten of these furnaces were in operation, and the consumption of fuel is said to have averaged 275 bushels per ton of ore smelted. This would be about 4,600 lb. per ton of ore, or over three tons per ton of pig iron.

About 1868 Norwegian ore containing 36 per cent of iron and 39 per cent of titanic acid was smelted in England by the Norwegian Titanic Iron Company ⁽²⁾ with coke for fuel. Red bricks were used in addition to limestone for flux, and the slag contained 36 per cent of titanic acid. The smelting was technically successful, but as nearly 3 tons of coke was needed per ton of pig iron, the operation was unprofitable and was given up after a few years.

From 1840 to 1856, two small charcoal furnaces, of 5 and 15 tons capacity, were operated successfully at Sanford lake in the Adirondack mountains ⁽³⁾, using ores with 8 to 15 per cent of titanic acid. Charcoal was used for fuel, and the slag contained 25 per cent of titanic acid.

In general, ores containing in the order of 10 per cent of TiO_2 were smelted without serious difficulty in small charcoal blast-furnaces using a mixture of silica and limestone for flux.

⁽¹⁾ A. H. A. Robinson, loc. cit., p. 26.

⁽²⁾ W. M. Bowron, loc. cit.

⁽³⁾ A. J. Rossi, "Titaniferous ores in the blast-furnace". Trans. Am. Inst. Min. Eng., 1892, Vol. 21, p. 832.

The consumption of charcoal was somewhat greater than with non-titaniferous ores, but probably no more than would be accounted for by the smaller percentage of iron in the ore and the larger volume of slag resulting from the presence of titanium and the necessary addition of silica. The increased consumption of charcoal was not due to any need for a higher temperature, as Bowron ⁽¹⁾ stated in 1882:

“The whole secret of working these ores successfully and continuously is to keep the heat so low as just to reduce the iron and not reduce the titanitic acid. The iron will be white, or at best mottled, if there is much titanitic acid to contend with. Titanitic iron is essentially a forge iron. Foundry iron can only be produced when the titanium is low, and then only by making a large quantity of cinder, so as to ‘wash’ the titanitic acid out of the furnace.”

SMELTING OF TITANIFEROUS ORES DISCONTINUED

As charcoal furnaces were replaced more and more completely by furnaces using coke, the smelting of titaniferous ores ceased. In smelting with coke the temperature is higher and this leads to the formation of infusible compounds of titanium which accumulate in the furnace and stop its operation. Where charcoal smelting was still practised, as in Sweden, competition with lower priced iron made it essential to use the richest ores that could be obtained and for this reason titaniferous ores are no longer used even in charcoal furnaces.

In respect to the troubles resulting from smelting these ores in coke furnaces, scarcely any real information is available, but the belief in these troubles was very definite. Auguste Rossi ⁽²⁾ quotes from the proceedings of a well-known scientific technical society (about 1880) “that one per cent of TiO_2 in a slag was enough to make it pasty to impossibility of tapping”, and “that the slags had to be pulled out with tongs”. Also, in a legal suit (in the 80’s) with respect to the use of ores containing one or two per cent of TiO_2 , a blast-furnace manager

⁽¹⁾ W. M. Bowron, loc. cit.

⁽²⁾ A. J. Rossi, “Development of the metallurgy of titanium”, *Met. & Chem. Eng’ng.*, 1918, Vol. 18, p. 117.

testified under oath that 0.75 per cent of TiO_2 in iron ore rendered it unfit for blast-furnace purposes, as it would be only a matter of a short time before the furnace would be 'clogged up' if the use of the ore were not stopped. Another testified that so little as 0.25 per cent of TiO_2 in an iron ore precluded its use in the furnace.

Rossi himself had been for eleven years in charge of furnaces smelting ores containing 1.5 per cent of TiO_2 and producing slags with 2 to 2.5 per cent, and knew that so small an amount of titanium had no appreciable effect on the working of the furnace.

EXPERIMENTS OF ROSSI

Auguste J. Rossi has been the most prominent champion of titanium, both in respect to the smelting of titaniferous iron ores and the production and use of ferro-titanium. In 1890 ⁽¹⁾ he gave an account of previous smelting operations, and he carried out experiments himself, at first on a small scale and later in a blast-furnace ⁽²⁾. In one of his later papers he says: "No difficulty will be experienced in smelting if the oxide of titanium (TiO_2) is regarded as so much silica and sufficient limestone is added to flux it off." This rather striking statement, which he made probably in view of the chemical similarity between TiO_2 and SiO_2 , has been quoted out of its context, and has obscured the fact that Rossi also said:

"Titanate of lime is more infusible than silicate of lime, and the addition of lime in excess, on general principles, may possibly, with ores very low in silica and containing a large amount of titanitic acid in the mixture, have caused the slag to prove less fusible; but a silico-titanate of lime, containing about equal percentages of silica, titanitic acid, and lime — 'sphene', as it is called — is as fusible in a blast-furnace as any good foundry-iron slag, and considerably more fusible than silicate of lime".

The slags Rossi made in his small blast-furnace in 1896,

⁽¹⁾ A. J. Rossi, "Titanium in blast-furnace." Jour. Am. Chem. Soc., 1890, Vol. 12, p. 91.

⁽²⁾ A. J. Rossi, "Titaniferous ores in the blast-furnace". Trans. Am. Inst. Min. Engrs., 1892, Vol. 21, p. 832.

A. J. Rossi, "The metallurgy of Titanium". Trans. Am. Inst. Min. Engrs., 1903, Vol. 33, p. 179.

show that Rossi did not actually treat TiO_2 as SiO_2 , but in fact, like other operators, used a mixture of CaO and SiO_2 to flux the TiO_2 , as is shown in the following table:

	I	II	III
Silica.....	15.9 to 17.5%	27.8%	26.7%
Titanic acid.....	34.4 "	36.2 "	25.1 "
Lime.....	22.1 "	24.4 "	25.8 "
Magnesia.....	9.7 "	0.6 "	6.0 "
Alumina.....	11.2 "	9.2 "	11.9 "
Iron oxide.....	4.3 "	1.8 "	3.5 "

I.—Slag made by Rossi in small blast-furnace at Buffalo, using coke.

II.—Slag made by Norwegian Titanic Iron Company, using coke.

III.—Slag from furnace at Sanford Lake, using charcoal.

In each case, it appears that the TiO_2 has replaced part of the lime as well as part of the silica that would have been present in a normal slag.

RECENT EXPERIMENTS

During recent years experiments have been carried on in the writer's laboratory and elsewhere, that have gone far towards clearing up the situation from a scientific point of view, although the work is still far from complete; the development may be traced as follows:

In 1915, the writer (¹) smelted in a small electric furnace a titaniferous magnetite from the Orton mine, Ontario, containing:

Iron.....	49.9 per cent
TiO_2	10.8 "
Al_2O_3	4.0 "
CaO	5.5 "
SiO_2	1.8 "

Depending on Rossi's statement that TiO_2 should be regarded as SiO_2 , enough lime was added to flux both of them. The resulting slag was barely fusible and the furnace could not be tapped, while part of the iron, which had penetrated the carbon lining of the furnace, showed on fracture the characteristic copper colour of titanium compounds. In view of this result, a number of fusibility tests were made by W. A.

(¹) Stansfield and Wissler, "The Smelting of Titaniferous Ores of Iron". Trans. Roy. Soc. Can., 1916, Series III, Vol. 10, p. 33.

Wissler, using test cones composed of mixtures of TiO_2 , SiO_2 , and CaO in varying proportions, but containing in each case 10 per cent of Al_2O_3 . The temperature at which each cone bent over was observed and was plotted on a triangular chart. It was found that slags containing about 20 to 30 per cent of TiO_2 , 20 to 30 per cent of lime, and 30 to 40 per cent of silica, with 10 per cent of alumina, were readily fusible, melting (or softening) at about $1,300^\circ$ to $1,350^\circ$ C. Low silica (20 per cent or less) or high lime (50 per cent or over) made the slags less fusible. A second smelting operation, using a charge proportioned in view of the information gained by these tests, gave a perfectly fluid slag carrying 20 per cent of TiO_2 .

The fusibility tests had been made without any special attention to the oxidizing or reducing gases in the furnace, and the test cones were sometimes light coloured and sometimes dark coloured after fusion. It was recognized that in the dark coloured cones the titanium must be present in a less oxidized state than TiO_2 . As this probability threw doubt on the accuracy of the results obtained, and as it was likely that reduction of TiO_2 to a lower oxide would take place in the blast-furnace, it was decided to repeat the work in a reducing atmosphere and to use the lower oxide of titanium in the cone mixtures.

In 1925, experiments on the reduction of TiO_2 were made in the writer's laboratory by heating this oxide in a stream of carbon monoxide to $1,000^\circ$ C. or $1,100^\circ$ C. in a carbon tube. A dark blue product was obtained which, in view of the loss of weight, was supposed to be Ti_3O_5 , an oxide that had been prepared by M. Billy ⁽¹⁾ by heating TiO_2 in hydrogen.

In 1926, the fusion tests were repeated by J. E. Morrison, using the dark blue oxide in the cones and maintaining an atmosphere of carbon monoxide in the furnace ⁽²⁾.

This work, which was done very carefully, showed a considerable range of slags having softening points at about $1,200^\circ\text{C}$., the range of composition being about 10 to 40 per cent TiO_2 , 20 to 40 per cent CaO , and 30 to 50 per cent SiO_2 ,

⁽¹⁾ M. Billy, "Contribution à l'étude du titane". *Annales de Chimie*, 1921, Vol. 16, p. 5.

⁽²⁾ Stansfield and Morrison, "Blast-furnace slags containing titanium". *Trans. Roy. Soc. Can.*, 1926, Section III, Vol. 20, p. 439.

as is shown in the figure. The temperature necessary for complete fusion of these slags would be about 50°C. higher than the points shown in the chart.

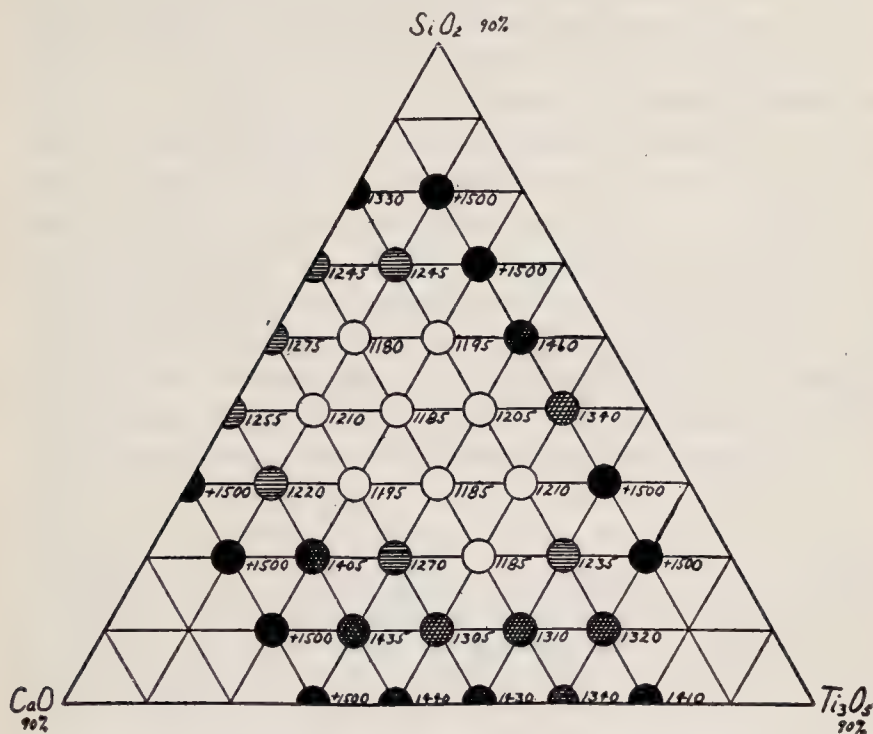


Figure 1. Softening points of mixtures of silica, lime and Ti_2O_3 with 10 per cent of alumina, in a reducing atmosphere.

In order to check the earlier work, mixtures containing TiO_2 were then tested in an oxidizing atmosphere. The results obtained were a little higher than when Ti_2O_3 was used, being about 1,200° to 1,250°C. for the same range of composition.

The results of these experiments, which are given in the paper by Stansfield and Morrison, should be accepted in preference to those of 1915. Some of the experiments in which the blue oxide was used were made in an atmosphere of carbon monoxide and nitrogen, such as would be present in the blast-furnace, instead of pure carbon monoxide, as in the earlier experiments. No difference was noticed in the softening points of the more fusible mixtures, but test cones that had been heated to 1,400°C., or over, were often copper coloured on the

outside, and in some cases the central part of these cones melted away while the skin was still unfused. It appears that when slags containing titanium are heated to $1,400^{\circ}\text{C}$. in nitrogen and carbon monoxide, a nitride or similar compound of titanium is formed, and that this is more refractory than the slag and tends to separate from it. As a check on this observation, some TiO_2 was heated to $1,400^{\circ}\text{C}$. in a carbon tube in a stream of carbon monoxide and nitrogen. Copper coloured and brass coloured products were obtained.

These experiments show that fusible slags can be obtained by heating mixtures of titanium oxide, silica, lime, and alumina in a reducing atmosphere, but that in the blast-furnace, where there is nitrogen as well as carbon monoxide, infusible titanium compounds will form, and will tend to separate from the slag, when it is heated above $1,400^{\circ}\text{C}$. It is also known that an infusible carbide is produced when titaniferous slags are heated in contact with carbon. These conclusions are in entire agreement with those drawn from blast-furnace smelting, namely, that in charcoal furnaces, operating at a moderate temperature, there was no difficulty in smelting titaniferous ores, but that in coke furnaces, where the temperatures are higher, infusible titanium compounds separate and clog the furnace.

During the past winter, W. E. L. Brown, from Cambridge, has been carrying on experiments in the writer's laboratory with a view to determining the exact composition of the dark blue oxide and of the nitrogen compounds of titanium that are formed at high temperatures. He experienced great difficulty in making these tests and his work has not been finished. His provisional conclusions were:

1. That the dark blue oxide is not Ti_3O_5 , but a higher oxide, perhaps Ti_4O_7 .
2. That when TiO_2 in a carbon boat is heated to $1,600^{\circ}\text{C}$. in a stream of carbon monoxide and nitrogen, a black compound, presumably titanium carbide, is formed where the oxide is in contact with the carbon of the boat, and that above this the oxide is converted into a copper coloured compound to which he provisionally assigned the formula Ti_5CN_4 .

As Mr. Brown did not obtain large enough samples for a satisfactory analysis, it may be mentioned that Moissan prepared the black carbide, TiC , by heating TiO_2 with carbon, and that he prepared a brass coloured nitride, TiN , and a copper coloured nitride, Ti_3N , by heating TiO_2 and carbon in nitrogen.

The early writers on the smelting of titaniferous ores assumed that titanium existed in the slag as TiO_2 , and it was natural to conclude, with Rossi, that, as this oxide is acidic like silica, it would form a titanate of lime in the slag; Rossi speaks of a silico-titanate of lime. More recent experiments show that, under conditions found in the blast-furnace, titanitic acid is reduced to a lower oxide, either Ti_3O or Ti_4O_7 . These oxides may be written as $\text{TiO} \cdot 2\text{TiO}_2$ and $\text{TiO} \cdot 3\text{TiO}_2$, and may be regarded as a compound of a basic and an acid oxide of titanium; which may explain why silica as well as lime is needed to produce a fusible slag.

Researches of W. M. Goodwin:

In 1920, W. M. Goodwin carried out at Queen's University a series of researches on the smelting of titaniferous ores, with the aid of a grant from the Advisory Research Council ⁽¹⁾. Using titaniferous magnetites with 10 to 20 per cent of TiO_2 , he carried out a number of smelting operations in a small electric furnace of 30 to 60 k.w., using sand for flux and charcoal for reducing reagent. The weight of ore smelted in each operation varied from 25 lb. to 100 lb. and was usually about 50 lb. The smelting of a charge containing 100 lb. of ore usually occupied three or four hours. The slags made were as a rule high in silica and titanium oxide, but, in the different tests, the silica in the slag was made to vary from 23 to 60 per cent. The melting temperature and viscosity of each slag was determined in a special apparatus, using an optical pyrometer. The most fusible slags, which became fluid about $1,300^\circ\text{C}$., contained about 36 per cent silica, 24 per cent TiO_2 , 12 per cent Al_2O_3 , 15 per cent MgO , and 5 per cent CaO . Counting the magnesia as lime, the analysis corresponds to

(1) W. M. Goodwin, "The smelting of titaniferous iron ores". Trans. Roy. Can. Inst., Toronto, 1921, Vol. 13, part 2, p. 35.

W. M. Goodwin, "A method of smelting titaniferous iron ore". Report No. 8 of the Hon. Advis. Council for Scientific & Indust. Research, Ottawa, 1921.

the most fusible area in Figure 1, and the temperature of 1,300°C. for 'becoming fluid' agrees sufficiently well with 1,200°C. for the softening point as determined by Morrison.

The pig iron produced with these slags contained about 2.5 per cent carbon, 4 per cent silicon, 0.2 per cent titanium, and 0.05 per cent sulphur. Goodwin concludes that titaniferous ores can be successfully reduced to pig iron in an electric furnace without the addition of limestone, using a slag that consists essentially of silica and titanium oxide, that the working temperature of these slags is not above that of the lime-silica slags used in the blast-furnace, and that the titanium-silica slags can probably be used in the blast-furnace.

With regard to these conclusions, it should be pointed out that the iron produced in these tests had, on the average, rather more than the allowable amount of sulphur, and that in spite of the use of charcoal and the considerable proportion of lime and magnesia in the ore. In the blast-furnace, using coke as fuel, it is almost certain that limestone would have to be added to carry the sulphur into the slag. Laboratory experiments should be made to show what amount of lime would be needed for this purpose, and whether it would make the slag unduly refractory.

The viscosity of the molten slags was tested in a special apparatus, and was found to be about the same as that of other Canadian slags at the same temperature. After fusion, however, the titaniferous slags commenced to effervesce, reacting with the graphite cup in which they were melted, and they became progressively less fusible. After some hours of contact with the carbon, the slags were barely fluid at 1,650°C. These reactions indicate the formation of the carbide, TiC , and possibly also of some nitride of titanium, as noted by Morrison and by Brown in the writer's laboratory.

Bachman Blast-furnace Test:

In 1914, under the direction of F. E. Bachman, of the McIntyre Iron Company, a test lasting more than two months was made with a 200-ton blast-furnace at Port Henry, N.Y. ⁽¹⁾. The furnace had been smelting a non-titaniferous magnetite

⁽¹⁾ F. E. Bachman, "The use of titaniferous ores in the blast furnace". Year Book, Am. Iron & Steel Inst., 1914, p. 371.

concentrate with coke for fuel, and in the test this magnetite was partly replaced by Sanford magnetite-concentrate containing 56 per cent of iron and 12 per cent of titanitic acid.

During the first month of the test, when foundry iron was being made, one-eighth of the ore was replaced by the titaniferous concentrate, so that the ore mixture contained 1.5 per cent of titanitic acid. The iron contained over 2 per cent of silicon and 0.5 per cent of titanium, the slag contained 3 to 4 per cent of titanitic acid. At a later period, when malleable iron was being made, one-fourth of the ore was replaced by the titaniferous concentrates, so that the ore mixture contained 3.0 per cent of titanitic acid. The iron contained 1.0 per cent of silicon and 0.45 per cent of titanium, the slag contained 4 to 6 per cent of titanitic acid. This must not be taken to mean that the production of a low-silicon iron was the *result* of adding the larger proportion of titaniferous ore, although the titanium did appear to reduce slightly the percentage of silicon in the iron; but the operators apparently considered that, when making foundry iron, 1.5 per cent of TiO_2 was as much as could safely be present in the charge, while when making malleable iron, 3.0 per cent of TiO_2 could be charged without serious difficulty. The iron made from a titaniferous charge was found to be slightly lower in sulphur than was usual, but the lower sulphur and silicon may perhaps be attributed to the slightly higher lime-silica ratio that was used with the titaniferous charge, as the operators followed to some extent Rossi's advice of considering titanitic oxide as silica.

Test bars were cast from the iron as it flowed from the furnace and it was found, comparing irons of equal silicon content, that the iron from a titaniferous charge was stronger than the iron from a non-titaniferous charge. The titaniferous iron also was found to make stronger castings when remelted by itself, or with scrap iron, than non-titaniferous iron of equal silicon.

When using the larger proportion of titaniferous ore, 'dirty hearth' conditions were sometimes observed, and the slag was seen boiling up in the furnace when the blast was off. The boiling was no doubt caused by reaction with the carbon in the hearth, and would be the same reaction as was noticed by Goodwin and by Brown in their researches. No serious

accumulation of titanium compounds appears to have taken place, as no accretions were found when the furnace was blown out at the end of the test. The consumption of coke was no higher with the titaniferous ore, and, with the smaller proportion of this ore (one-eighth of the whole), the slag was more fluid than usual.

The results of this test have been published widely as demonstrating that titaniferous ores can be smelted in the blast furnace, but it should be pointed out that the ore charge used in making foundry iron only contained 1.5 per cent of TiO_2 and, when making malleable iron, the mixture only contained 3.0 per cent of TiO_2 . Dulieux ⁽¹⁾ states that ores containing no more than 3 per cent of titanium are accepted by any iron-works manager, and that 2 or 3 per cent of titanium in an iron ore is not believed to cause any trouble in smelting. It may be doubted whether an ore having 3 per cent of titanium would be accepted at the present time by iron-works managers, but, by way of comparison, it may be mentioned that Rossi smelted in a coke blast-furnace ores containing 20 per cent of TiO_2 , and his slags contained 34 per cent of TiO_2 .

From a commercial point of view, large scale demonstrations using moderate proportions of titaniferous ores are no doubt the most effective, but to obtain a scientific knowledge of the best methods of smelting such ores, larger proportions must be used. In view of the fusibility chart shown in Figure 1, it is clear that experimenters should try to find how *little* lime they need to keep the sulphur out of the iron, instead of adding lime to flux the titanium.

SMELTING MAGNETITES

One objection to titaniferous ores is that they are usually magnetites, and on that account, even if non-titaniferous, they would be more difficult and costly to smelt than ordinary hematite ores. Comparatively little has been published with regard to the smelting of magnetite, but it is known that,

⁽¹⁾ P. E. Dulieux, loc. cit.

although the iron is in a lower state of oxidation than in hematite, more fuel is needed to effect its reduction, and that this is due to the higher temperature and longer time that is needed for the reduction of magnetite by carbon monoxide. On account of this difference, magnetite ores need different treatment in the blast-furnace, and for this reason it is not desirable to mix hematite and magnetite ores. As an example, it may be mentioned that, in the smelting test at Port Henry, the 'burden' (ratio of ore to coke) was only 1.45, while with easily smelted hematite ores the burden is about 2.0 when making foundry iron and 2.2 when making basic iron. This difference is due in part no doubt to the smaller size of the Port Henry furnace, but it indicates a very real handicap on the use of these ores. The consumption of coke was 2,500 lb. per ton of foundry iron and 2,300 lb. per ton of malleable iron.

On the other hand, magnetite ores can be concentrated very readily by magnetic methods after crushing, and the magnetic concentrate can be sinter-roasted to put it in suitable condition for smelting, at the same time removing the greater part of any sulphur that may be present. The sintered concentrate is found to be readily reducible in the furnace, behaving more like a hematite than a magnetite, and can suitably be added to the charge of a furnace smelting hematite.

POSSIBILITY OF THE COMMERCIAL USE OF TITANIFEROUS ORE

Titaniferous magnetites are not smelted at present, partly because they are titaniferous, partly because (in consequence) they are rather low in iron, and partly because they are magnetites. By magnetic concentration, they can be made a little richer, but the titanium oxide is still from 5 to 10 per cent, which is too high for economical smelting of the unmixed ore. It is clearly undesirable to use quartz as a flux, as was done by the early operators, but by mixing the concentrate with siliceous ores and using the minimum amount of limestone, it may be possible to obtain economic results. It is not considered desirable to mix magnetites and hematites, and to supply enough non-titaniferous magnetites for mixing would introduce other difficulties; but the concentrates, when sinter-roasted,

will probably be easily reduced and can therefore be smelted in admixture with siliceous hematites for the production of a superior grade of pig iron.

Further research is needed, both in the laboratory and the blast-furnace, before this possibility can be regarded as a certainty, and it is clear that the suggested treatment of titaniferous magnetites should not be undertaken until the way has been paved by the utilization of non-titaniferous magnetites.

INTRODUCTORY REMARKS AND DISCUSSION

In submitting his paper for discussion, Dr. Stansfield said:

Mr. Chairman, ladies and gentlemen: In view of the somewhat limited supplies of high-grade iron ores in Canada, and of the large quantities of iron ores that are titaniferous in character and are therefore not employed at present, it has been of some interest to investigate the possibility of smelting these latter ores. The information we have with regard to the smelting of titaniferous ores is very contradictory. Some writers claim that, if suitably fluxed, they are very easily smelted; on the other hand, many blast-furnace managers consider that even the smallest trace of titanium makes such an ore impossible to smelt. In view of this, although there is no immediate probability of the utilization of such ores in this country, I have, for a number of years, been carrying on researches on the effect of titanium on iron ores.

Summarizing the work quite briefly, we found that titanium in ores could be easily fluxed, as suitable mixtures of titanium oxide, lime, and silica are quite fusible. Titanium occurs ordinarily as TiO_2 , and Rossi, a well known writer on the subject, no doubt on account of the similarity between TiO_2 and SiO_2 , assumed that the oxide TiO_2 should be fluxed like silica. Our work showed that that is not the case and we have found an explanation in the fact that titanium is present in slags not as TiO_2 at all, but as a somewhat lower oxide. This oxide is dark coloured and not white like TiO_2 . It is probably some mixture or compound of TiO and TiO_2 .

We carried out researches on the melting points of mixtures of this dark oxide of titanium with lime and silica, making our experiments in an atmosphere of carbon monoxide in order to keep the titanium in the right degree of oxidation. We obtained quite fusible mixtures. After this we used nitrogen in our test chamber, in addition to carbon monoxide, in order to approach more closely the conditions in the blast furnace. We found that when nitrogen was present and the furnace was heated rather strongly, the mixtures became infusible, and we realized that we were getting infusible nitrides and carbides of titanium. In this way our more recent work has shown a reason for the very great difference between the opinions held by different workers.

It is quite true that there are fusible mixtures of titanium oxide, lime, and silica, but on the other hand, if these are heated strongly in the presence of nitrogen and carbon, infusible products may result. Our work is not finished and I have indicated in my paper some directions in which I think research work should be carried further.

Titaniferous iron-ores are in general magnetites. In smelting them we have two troubles. There is not only the fluxing of the titanium itself, but there is also the additional difficulty that applies to smelting any magnetite. It will be necessary to take up the smelting of magnetites before undertaking the smelting of titaniferous magnetites. The magnetites themselves will no doubt be smelted before long, probably with the aid of magnetic concentration followed by sintering of the concentrate, which will put it in a condition suitable for smelting.

In conclusion I should like to mention that I have received a discussion of my paper from Mr. Harald Skappel of Oslo, referring to the practice in Norway. He points out that in Norway most of the titaniferous ores contain small percentages, from 0.1 per cent to 0.8 per cent of vanadium and the smelting of these ores is conducted with a view to the recovery of this valuable ingredient.

THE CHAIRMAN (MR. J. L. AGNEW): This paper is now open for discussion. We would be glad to hear from any of the members in regard to Dr. Stansfield's paper.

PROFESSOR GEO. H. STANLEY (Johannesburg): I have read this paper of Dr. Stansfield's, which I only received yesterday, with a great deal of interest. I am quite sure it is a most valuable contribution to the literature on this subject.

In South Africa, when I went there first about twenty-two years ago, there was some talk, even at that early date, of utilizing the iron-ore resources of the country, but everyone held the opinion that the iron ores available were all titaniferous and useless for that reason. It occurred to me that that was a very useful subject for research, and from that time on I did quite a little work on the subject, even as Dr. Stansfield and others have done in other parts of the world.

About 1909, I think it was, I put the observations on record. Curiously, I found just the same facts that Dr. Stansfield has referred to, in that during smelting in reducing atmosphere, the TiO_2 becomes partly reduced. I could not determine exactly to what degree it was reduced, so I assumed it was probably Ti_2O_3 , and figuring that it functioned as a base instead of an acid, it was possible to make mixtures that were very easily fusible. Those mixtures which had a melting point of $1,000^\circ\text{C}$. in a reducing atmosphere would have their melting point increased to $1,200^\circ\text{C}$. on oxidation. It was quite possible to change it, so to speak, by varying from oxidizing to reducing atmosphere and make apparently the same mixture vary all that difference in degrees in its melting point.

Soon afterward it became obvious that a great deal of other iron ore, hematite ore and magnetite ore, which are non-titaniferous, was available in South Africa; so that the commercial importance of working on titaniferous ores diminished and, in fact, disappeared. I stopped the work. But during the war, when we were cut off practically from outside supplies of iron, it became necessary to see what we could do in the question of smelting iron ores for ourselves in South Africa.

A small iron blast-furnace, quite a baby, ten tons daily capacity, was put up in Pretoria and functioned quite well on the hematite available. When that was shut down, it was decided to carry out a series of experiments, utilizing the titaniferous ores which occurred nearby and using as a basis for fluxing calculations the conclusions I had previously come

to. We found those conclusions confirmed on the large scale. We were able to run slags running up to between seven and eight per cent of titanium (figured as Ti_2O_3) if I remember correctly. Having proved that point, the test was not carried any further. It was, however, interesting that, when the furnace was dismantled, a bear of spinel-rich material was found in the hearth of the furnace. I think it was undoubtedly due to the fact that we were using a good deal of aluminous ore also, a clay-band ore which also was found in Pretoria. I think it was in a German publication that I found reference to the same fact, i.e., that high alumina and titanium simultaneously would produce infusible spinel. That may afford another explanation than the conclusion reached by Dr. Stansfield.

There is one other possible utilization for this titaniferous ore which I might mention. Of course, the future of any iron industry lies in the production of steel and not cast iron in these days. So, on the laboratory scale in an electric furnace, we tried to see if we could not use the ore as a de-oxidizing agent in converting phosphoric pig-iron to reasonably good steel. We found that it could be so used. That was of importance, because the ore was low in sulphur and available at a very cheap rate.

There was another possible advantage. This titaniferous ore, as has been mentioned in another connection, is quite rich in vanadium. I think up to nearly one-half of one per cent of vanadium has been recorded in this South African ore. If that could be introduced into the steel, it would obviously improve the quality of the steel immensely.

DR. W. L. GOODWIN (Canada): I have been very much interested in Dr. Stansfield's paper because my son, W. M. Goodwin, and I some years ago attacked the problem of titaniferous iron ores from a point of view that has been suggested more than once in this discussion; that is, from the point of view of the slag that might be made to slag off the titanium oxide.

His way of attacking the problem was by looking at the nature of titanium itself, really from the point of view of its position in the Periodic system of the elements. He noticed that it occupied an intermediate position and thought that,

therefore, it could be slagged off as a base as well as an acid oxide. He succeeded, as Dr. Stansfield has pointed out in his paper, in making slags with a very high percentage of silica in them and the whole of the titanium. He did not investigate the state of oxidation of the titanium. His work was really directed mostly towards utilizing the content of vanadium. He succeeded in saving the whole, or practically the whole, of the vanadium in pig iron made from titaniferous ores containing from 0.2 of one per cent to nearly one-half of one per cent. The further work with pig iron made in that way was most interesting.

I should mention that, in making this pig iron, he used highly silicious slag. He actually added silica in the form of sand as his flux. As I said, the further work with this pig iron was most interesting because he succeeded in transforming that pig iron—he was working on a fairly large scale, a ton scale—into steel without losing the vanadium.

It seems to me that work of this sort and that which Dr. Stansfield has so well described might form the basis of a vanadium-steel industry, putting the vanadium directly from the ore into the steel, without making ferro-vanadium.

Reference has been made to the project of making ferro-vanadium. That might be, under some circumstances, advisable, but you see at once that it would be a better commercial project to throw the vanadium directly into the pig iron and steel without going to the trouble of extracting it as ferro-vanadium.

THE CHAIRMAN: Dr. Stansfield's paper is very pertinent, I think, at this time. If the smelting of titaniferous ores were made feasible in Canada, it would make available a great many million tons of iron ores.

Dr. Goodwin speaks of the vanadium. I just wonder how much vanadium appears in steel. You make a vanadium steel and you analyze it. Does it really carry any appreciable amount of vanadium? Does not the vanadium act as a scavenger, in other words? Is not that its real use in steel?

DR. LEO HENDERSON: What percentage of titanitic acid was present in the ores which were the subject of the experiments? It would be very interesting to know that.

PROFESSOR STANLEY: If I might speak from my own experience, the content was around twelve or fifteen per cent. But I do not think it is always the case that titanium is present as TiO_2 ; there is evidence that some of the ores contain it as Ti_2O_3 .

DR. GOODWIN: The ores used in the experiments I described contained from nine to fifteen per cent of titanium. They were very high in titanium and were selected for that reason.

DR. STANSFIELD (Communicated): The experiments described in my paper were not made on natural ores but on artificial mixtures of titanium oxide, silica, lime, and alumina. The mixtures tested contained up to seventy per cent of TiO_2 , and easily fusible mixtures were obtained with as much as forty per cent of TiO_2 .

CONTRIBUTED DISCUSSION

MR. HARALD SKAPPEL*: Here, in Norway, the smelting of titaniferous magnetite has of late received new impulse through the discovery that these ores often have an exceptionally high content of vanadium, the value of which, if it could be recovered economically, exceeds the value of the iron content of the ore. For the recovery of vanadium from such ores there already exist several patented processes, some of which aim at extracting the vanadium as such, while others combine the extraction of vanadium with the iron-smelting process. Among the latter I will mention the process of the Swedish inventor, Rutger Henrik von Seth, of Stockholm (Norwegian Patent No. 41005), because it gives an insight into the metallurgical behaviour of vanadium in the iron-smelting processes. It is a process for "the recovery of vanadium compounds, or vanadium, from pig-iron containing vanadium, by oxidation, during the first part of the refining process, as a slag containing vanadium", and is characterized by the fact that the oxidation is interrupted at a certain point in the decarburization process when the whole or the greater part of the vanadium has passed into the slag, which is then tapped and the decarburization of the pig-iron continued.

*Consulting Metallurgist, Oslo den Skar, Maridalen, Norway.

The patent mentions that vanadium oxidizes before other constituents of the pig-iron and therefore has a tendency to accumulate in the slags of the pig-iron-mixer, if it is not removed before entry into the mixer.

Thus the smelting of titaniferous ores of iron has in most cases to be conducted with due regard to the recovery of their vanadium content. In different Norwegian titaniferous iron ores, this varies between about 0.1 per cent and 0.8 per cent, and it has been found to be present chiefly in the magnetite of the ore, so that, in magnetic concentration, the magnetite fraction contains practically the whole of the vanadium content of the original ore.

In the smelting of such ores for iron, one of two things may happen to the vanadium: (a) it may, by reduction, pass into the iron; or (b) it may pass into the slag. Vanadium being an element that is very hard to reduce to the metallic state, it would, in the ordinary iron-smelting process, pass entirely into the slag, were it not for the fact that it has, also, a great affinity for carbon. As a result of this, it enters the pig-iron in the form of carbide. But the specifications of the von Seth process indicate that even this entry of vanadium into the pig-iron as carbide requires a somewhat *high degree of reduction* of the iron smelting slag, and the possibility, by working under conditions yielding slags of *low degree of reduction*, to drive the entire vanadium content of the ore into the slag and yet produce pig-iron.

Experience gained from electric smelting in Norway has taught that even by a high degree of reduction of the slag, sufficient for excellent desulphurization, the vanadium content of the ore will not exclusively accumulate in the pig-iron and the slag, with consequent loss of part of the vanadium in the desulphurization slag. Therefore it seems more practical to work in such a way as not to drive the vanadium content of the ore into the pig-iron, but to allow it to accumulate in the slag and afterwards work the slag up for vanadium.

As already explained, this may be accomplished by keeping up a definite, somewhat low, degree of reduction of the smelting slags. In doing so it is evident that, simultaneously, the desulphurizing effect of the slag is lowered, as, with

decreasing degree of reduction of the slag, the coefficient of division of sulphur between slag and metal is lowered. In the opinion of the writer, the reason for the bad desulphurization by slag of low degree of reduction, i.e., slags of comparatively high FeO content, is the fact that in such a system sulphur is present chiefly as FeS, which is a sulphide of metallic appearance and qualities, readily soluble in metallic iron and only very slightly soluble, in silicate slags. By increasing the degree of reduction of the slag, as, for example, according to the reaction:



the iron sulphide is changed into calcium sulphide, which is of non-metallic appearance and qualities, insoluble in metallic iron, but very soluble in basic or neutral silicate slags. If to such a slag FeO is added, the following reaction will take place:

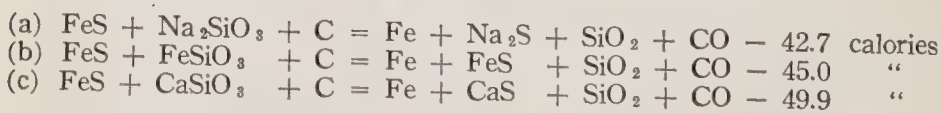


and sulphur will again pass into the iron. Thus, if we are working with slags of low degree of reduction, it is evident that a sufficient desulphurization of the pig-iron can only be attained if the raw materials going into the furnace are low in sulphur.

In the light of the experiments of Prof. A. Stansfield, as outlined in his paper, it is evident that the chief difficulty in the smelting of titaniferous iron ores—the formation of infusible titanium compounds—is due chiefly to two causes, namely, to the formation either of titanium carbide or of titanium nitride, both occurring at high temperatures in strongly reducing surroundings. He also mentions that these difficulties were not present when the ore was smelted in charcoal furnaces at low temperature (and a consequently low degree of reduction of the slag), but became conspicuous in the coke-blast-furnace using hot blast, and, for the sake of desulphurization, high temperature and consequent high degree of reduction of the slag. Neither the carbide nor the nitride of titanium seem to be able to exist in a slag of low degree of reduction, i.e., one of comparatively high FeO content. Thus we see that the requisite for easy slagging of the titanium content of the ore is the same as for complete slagging of the vanadium content.

With regard to phosphorus, it is known that it behaves quite the opposite to sulphur, in that increasing degree of reduction of the system has a tendency to drive the phosphorus from the slag into the iron, while a low degree of reduction of the system drives phosphorus into the slag. Common to phosphorus and sulphur is the fact that the tendency of both to go into the slag increases with increasing basicity of the slag.

Thus the most rational way of smelting titaniferous ores of iron which also contain vanadium, seems to be to smelt them under such conditions that there result a pig-iron of somewhat low silicon content (white-iron) and a slag of definite, somewhat low, degree of reduction, which will take up the vanadium content and the titanium content of the ore. Under such circumstances a sufficiently low sulphur content of the pig-iron can only be attained by using raw materials low in sulphur, or raw materials which have undergone desulphurization before entering the smelting furnace. In this connection I will mention the desulphurization of iron ores in the concentration process and in the following sintering process. If coke is used, the possibility of diminishing its sulphur content will have to be considered. The desulphurizing effect of the slag during the smelting process may also be increased, for instance, by increasing the basicity. The present writer proposes a further step, namely, the addition of alkali in low percentage. Such addition is likely to have a very beneficial effect in lowering the melting point of the slags and, besides that, in improving the coefficient of division of sulphur between the slag and the pig-iron, when the degree of reduction of the system is low. The reason for this will be seen by comparison of the following reactions:



which show that the transfer of sodium from silicate to sulphide requires even less energy than does the similar transfer of iron; so that, even in a slag of low degree of reduction,

sodium will take possession of some sulphur with formation of sodium sulphide, which is of non-metallic nature, insoluble in metallic iron, but readily soluble in basic silicate slags. It also lowers the metallic qualities of FeS, with which it forms sodium sulpho-ferrites, and thus also drives more FeS into the slag.

However, if the content of vanadium in the ore is high, and if it is of prime importance to recover it in as concentrated a form as possible—and especially if the slag is afterwards to be worked up direct for ferro-vanadium—the smelting may with advantage be conducted without regard to the sulphur content of the pig-iron, or even in such a way as purposely to drive sulphur and phosphorus into the pig-iron in order to keep these elements out of the slag, or to avoid diluting the slag with other materials. The resulting pig-iron must then be desulphurized afterwards in a second operation, in an electro-thermic furnace, for example, and simultaneously changed into an iron of definite quality. The same way of working will also be of advantage when the raw materials used are so high in sulphur that, under the conditions employed, a sufficiently desulphurized pig-iron is not attainable in one operation—for instance, when operating a blast-furnace with coke under such conditions that there results a slag of low degree of reduction.

When working in this latter way, i.e., producing pig-iron (or other kinds of iron) in two operations by first smelting and afterwards desulphurizing, one has the advantage of being able to work with a very small amount of slag, the gangue of the ore being removed as far as possible by dressing before smelting and no flux being necessary in order to maintain the requisite basicity. Only for the purpose of lowering the melting point of the slag a little flux may be necessary, and also in this case the addition of a small amount of alkali may recommend itself.

Here in Norway the problem of the electric smelting of iron ores, using cheap coke as reduction carbon, is believed to have been technically and economically solved by the new furnace which has been tested by the Norwegian Govern-

ment in co-operation with Christiania Spikerverk A/S. The latter firm has at present at its works in Nydalen, near Oslo, a 5,000-k.w. furnace running successfully and producing pig-iron of highest quality. The firm has recently acquired the Rödsand mine—a body of titaniferous iron ore with comparatively high vanadium content—and has also secured new water-power at Bremanger, where the erection of a 10,000-k.w. furnace for the purpose of smelting the ores from Rödsand is said to have been definitely decided upon.

PROCEEDINGS. PART IV

IRON AND STEEL

PERSONAL INDEX

	PAGE
Arnold, Professor, work of, on manganese alloys.....	108, 127, 130, 155
Aston, J., work of, on alloys of iron and manganese.....	109, 135-6
Bachman, F. E., work of, on titaniferous iron ores.....	564-6
Bain, H. Foster, quoted, future demand for metals.....	32
Baker, William, quoted, manganese in steel	65
Barrett, quoted, manganiferous iron ores	6
Bathgate, R. G. M., quoted, tonnage of coking coal in Jharia coal-field...	191-2
Bell, Sir Lowthian, quoted, manganese steel.....	65-6
Bergius, Frederick, quoted, distillation of coal.....	233-4
Bessemer, Sir Henry, ref., work of, on manganese.....	61-2, 69
Bowron, W. M., quoted, titaniferous iron ores.....	556, 557
Boyle, Hon. Robert, reputed discovery of manganese mine by.....	10-11
Boylston, quoted, importance of manganese in the steel industry.....	6
Brown, Coggin, quoted, ash content of Indian coals.....	225, 226
“ “ “ composition of Indian coals.....	230
“ “ “ tin ore in India.....	264-5
“ “ “ tungsten ores in India.....	243-4
Brown, W. E. L., ref., titaniferous iron ores.....	562-3
Burgess, C. F., ref., alloys of iron and manganese.....	109, 135-6
CAMERON, A. E., joint-author, paper, <i>The Impact Resistance of Steels at Low Temperatures</i>	533-551
Campbell, A. N., quoted, anodic behaviour of ferro-manganese.....	46
CARRIE, G. M., joint-author, paper, <i>Magnesia Refractories for Steel Furnaces</i>	435-521
Davis, Herbert W., quoted, production of ferro-manganese in the United States.....	40
Faraday, work on alloys of iron quoted.....	97
Fermor, L. L., quoted, manganese resources of India.....	248
Fischer, Franz, quoted, liquid fuels from coal.....	232-3
Forbes, David, quoted, determination of manganese in steel.....	64
FOX, CYRIL S., paper, <i>India's Resources in Raw Materials for a Domestic Iron and Steel Industry</i>	163-279
Gautier, Ferdinand, quoted, manganese steel.....	106
Goodwin, W. L., disc., Smelting Titaniferous Ores of Iron.....	571-2, 573
Goodwin, W. M., work of, on titaniferous iron ores.....	563-4, 571-2
Guillet, L., work of, on manganese alloys.....	107, 127-9, 131
HADFIELD, SIR ROBERT, BT., paper, <i>Low-Carbon Alloys of Iron and Manganese</i>	93-162
HADFIELD, SIR ROBERT, BT., paper, <i>Manganese, the Ores and the Metal; with an account of the History and Production of Ferro-Manganese</i>	1-92
Hall, A. L., quoted, Postmasburg manganese deposits.....	27
Holland, Sir Thomas, quoted, international interests in raw materials...	44
“ “ “ mineral resources of the Empire.....	3-4

	PAGE
Hopkinson, B., work of, on magnetic properties of iron and its alloys....	141
Hotchkiss, W. O., quoted, life of Lake Superior iron-ore deposits.....	22
Hoy, Sir William, quoted, extent of South African manganese deposits.	28
Jones, H. C., quoted, hematite in India.....	183-4
Joseph, T. L., quoted, manganiferous iron ores.....	6, 35-7
Kapffe, Carl, quoted, reserves of Lake Superior manganiferous iron ores.	6
Kasé, T., work of, on special steels.....	110, 132, 135, 155
Kinney, S. P., quoted, manganiferous iron ores.....	35-7
Kitson, Sir Albert E., quoted, manganese ore deposits of Gold Coast....	6, 23-6
Kohn, Ferdinand, quoted, alloys of iron and manganese.....	67-8, 70-2
Langenburg, F. C., quoted, properties of steel at low temperatures.....	533-4, 535-6
Lathbury, G. C., work of, on coking coals.....	212
Magniny, G., quoted, ferro-manganese.....	78-9
Marshall, G. W., work of, on coking coals.....	212
Menelaus, William, quoted, work of Robert Mushet.....	77-8
MORRISON, I. F., joint-author, paper, <i>The Impact Resistance of Steels at Low Temperatures</i>	533-551
MORROW, J. G., paper, <i>The Cascade Method of Pouring Steel</i>	522-532
Mushet, David, quoted, alloys of manganese and iron.....	73-4, 101
Mushet, Robert, quoted, alloys of manganese and iron.....	98
“ “ “ manganese in steel.....	75-7
Osmond, Floris, quoted, manganese steel.....	98-9
PASCOE, C. F., joint-author, paper, <i>Magnesia Refractories for Steel Furnaces</i>	435-521
Pascoe, E. H., quoted, coal and iron-ore resources of India.....	216
Penman, David, quoted, Jharia coal-field reserves.....	206-7
Pepper, J. H., quoted, manganese.....	11
Perin, C. P., quoted, iron-ore reserves adjacent to Bengal coal-fields....	183
Pourcel, Alexandre, quoted, ferro-manganese.....	72, 79-84
“ “ “ ref.....	106-7
Purdy, R., work of, on Raniganj coals.....	210-1
Reynders, John V. W., quoted, manganese resources in relation to domestic consumption.....	5-6
“ “ “ Western Georgia manganese-ore deposits.....	21-2
Robinson, A. Dawes, coal analyses by.....	195-200, 204
Robinson, A. H. A., quoted, Canadian occurrences of titaniferous iron ores.....	554-5
Rosenhain, W., work of, on manganese alloys.....	118
Rossi, Auguste I., work of, on titaniferous iron ores.....	558-9
Royston, P. H., quoted, utilization of manganiferous iron ores.....	35-7
Skappel, Harald, disc., smelting titaniferous ores of iron.....	573-8
Spurr, J. E., quoted, importance of manganese supplies.....	37-8
Stanley, George H., disc., smelting titaniferous ores of iron.....	570-1, 573
STANSFIELD, ALFRED, paper, <i>Smelting Titaniferous Ores of Iron</i>	552-578
Stead, J. E., quoted, spiegel and ferro-manganese.....	88
Strauss, Jerome, work of, on manganese steels.....	110-1, 155

	PAGE.
Tata, J. N., steel works founded by.....	167, 281-2
Thomas, J., quoted, Bokaro coal-field.....	214, 215
Tyler, P. M., quoted, ferro-manganese requirements for steel industry...	20
Willcox, F. H., quoted, position of United States in regard to supplies of manganese.....	33-5, 47
Wood, C. E., quoted, manganiferous iron ores.....	6
Yamada, R., quoted, steel at low temperatures.....	536-7
YANESKE, B., paper, <i>The Manufacture of Steel in India by the Duplex Process</i>	281-434
Zereteli, Datiko, quoted, manganese ore.....	14-6

GENERAL INDEX

	PAGE		PAGE
AGRARIAN industry, the.....	165, 182	analyses, open-hearth slag.....	416-7
agrarias.....	165, 182	“ pig iron (Tata).....	354-5-6
air-pressure recording chart.....	367	“ producer gas.....	351
alloys, low-carbon, of iron and		“ quartzite, India.....	249, 259
manganese.....	93-162	“ salamander slag.....	382
see under <i>low-carbon alloys</i> .		“ silica-brick, India.....	344
analyses, bauxite, India.....	253	“ silica-clay, India.....	344
“ blast-furnace slag.....	359	“ spiegel (Tata).....	357
“ chromite, India.....	253, 341	“ ladle, of steels.....	538
“ “ bricks.....	341	annealing moulds, composition of	421
“ coal, Assam.....	216	apatite, India.....	240
“ “ Bokaro.....	215	Assam coal-field.....	215-6
“ “ Giridih.....	195-200	Australia, magnesite deposits	
“ “ India.....	350	of.....	479-481
“ “ Jharia.....	202-5	Austria, magnesite deposits of...	461-5
“ “ Raniganj.....	213	BADAMPAHAR, hematite deposits	332
“ coke, India.....	230, 350-1	bauxite, India.....	250, 252-3
“ coke, natural (jhama).....	230-1	Bengal Iron Co., Ltd., plant and	
“ converter slag, 371, 373, 375,		operations of.....	268-270
378, 381, 382, 383		Bengal Iron Co., Ltd., minor ref.	168
“ dolomite, India.....	237, 337	benzol plant, Tata.....	303
“ ferro-manganese (Tata).....	357	berginization.....	233
“ ferro-phosphorus.....	358	Bessemer converters, Tata.....	314-5
“ fire-brick, India.....	345	blast-furnace slag, analyses.....	359
“ fire-clay, India.....	255, 344	blast-furnaces, Tata.....	283, 285-6,
“ ganister, India.....	343	308-312	
“ hematite, India.....	331, 332	blooming-mill, Tata.....	288-290, 307
“ hydromagnesite, Can-		blower-house, Tata.....	315-6
ada.....	466-7-8	bog manganese.....	43
“ iron-manganese alloys,		Bokaro coal-field.....	214-5
low-carbon, 113-7, 123,		braunite.....	43
128-130, 134, 135, 146, 154		Brazil, manganese ores of.....	13, 14
“ iron ore, India.....	185, 331-2	Brinell hardness, of low-carbon	
“ limestone, India.....	236-7-8, 335	ferro-manganese alloys.....	
“ magnesite.....	338	115-7, 124-5, 128, 134, 154	
“ “ Australia.....	480-1	Bristol pressure-recording chart..	367
“ “ Austria.....	462	CAKING-Coal, term defined.....	190
“ “ Canada.....	468	calcining plant, Tata.....	327-330
“ “ Cyprus.....	481	Canada, magnesite.....	465-8
“ “ Greece.....	475-6	“ manganese ores.....	16-7
“ “ India.....	477	“ titaniferous iron ore....	554
“ “ Italy.....	473	carbon dioxide, from magnesite..	440
“ “ Manchuria.....	472	carbon-free manganese.....	90-2
“ “ Norway.....	472	Cascade Method of Pouring Steel,	
“ “ South Africa.....	481	The (J. G. Morrow).....	522-532
“ “ United		“ equipment.....	523-6
States...469, 470		“ operation.....	526-9
“ magnesite bricks.....	340	results.....	529-532
“ manganese.....	119	cassiterite, India.....	264
“ manganese ore, India.....	245, 334	casting house, Tata.....	325
“ mica schist, India.....	342		
“ mixer slag.....	361		

- | | PAGE | | PAGE |
|--|-----------------|--|----------------|
| Charpy impact tests on steel . . . | 539-541 | to Bessemer converters . . . | 359-362 |
| china-clay, India | 256 | to open-hearth tilting furn- | |
| chromite, India | 242, 253, 341 | aces | 362-388 |
| clay-ironstone, India | 181-3 | to casting house | 388-421 |
| coal, cleaning of | 225 | to stripper yard | 421-6 |
| “ Tata Duplex plant | 349-350 | to soaking pits | 426 |
| coal-fields of India | 190-222 | dwi-manganese | 51 |
| coal-tar, Tata Duplex plant | 352-3 | | |
| coke, natural, India | 230-2 | ELECTRICAL qualities of low-carbon | |
| “ soft, India | 228-230 | iron-manganese alloys . . | 137-145, 146 |
| “ Tata Duplex plant | 350 | | |
| coke-oven gas, Tata plant | 352-3 | FERRO-MANGANESE, the history | |
| coking-coal, India | 190-218 | and production of | 1-92 |
| columbite, new elements in | 51 | see also under <i>manganese, the</i> | |
| converter bottom house, Tata . . . | 316-7 | ores, etc. | |
| converter slag, analyses | | “ “ “ low-carbon al- | |
| 371, 373, 375, 378, 381, 382, 383 | | loys. | |
| corrodibility of low-carbon iron- | | analyses | 59, 73, 89 |
| manganese alloys | 156-8 | as material for anodes | 46 |
| crude oil, Tata Duplex plant | 353 | consumption, Canada | 17 |
| cyanite, India | 263 | “ United States | 33 |
| Cyprus, magnesite deposits of . . . | 481 | exports, from Canada | 18, 40 |
| | | history of | 60-84 |
| DIALOGITE | 43 | imports, Canada | 17 |
| dolite, composition of | 459 | “ United States | 33, 40 |
| dolomite, India | 239, 254, 335-8 | manufacture of | 84-90 |
| “ properties and uses of | 456-460 | makers of, British | 88-9 |
| Duplex charge, particulars of . . . | 400-4 | production, British | 89 |
| “ “ rail steel | 403-4 | “ cost of | 82 |
| “ “ structural steel | 402-3 | “ United | |
| “ “ tin-bar steel | 400-1 | States | 18, 33, 40 |
| Duplex plant of the Tata Co. . . . | 308-330 | “ world | 12 |
| Bessemer converters | 314-5 | requirements, world | 20, 32 |
| blast furnaces | 308-312 | ferro-manganese for Tata plant . . | 356 |
| blower house | 315-6 | ferro-phosphorus for Tata plant . . | 357 |
| calcining plant | 327-330 | ferro-silicon, for Tata plant | 357 |
| capacity | 429 | fire-clay, India | 255-7 |
| casting house | 325 | “ used in Tata plant | 343 |
| converter bottom house | 316-7 | fluid fuel from coal | 232-4 |
| gas producers | 323-5 | fluorspar, India | 241 |
| hot metal mixer | 313 | “ used in Tata plant | 342 |
| open-hearth furnaces | 317-322 | fluxes, for India's iron and steel | |
| “ “ output of | 428-431 | industry | 234-241 |
| pig casting plant | 312-3 | franklinite | 43 |
| production, steel ingots, 1926 . . | 431 | fuel, fluid, from coal | 232-4 |
| waste heat boilers | 322 | Fuller's earth, India | 256 |
| Duplex Process, <i>The Manufacture</i> | | | |
| <i>of Steel in India by the</i> (B. | | GANISTER, used in Tata plant . . . | 343 |
| Yaneske) | 281-434 | gas producers, Tata plant | 323 |
| see under <i>manufacture of</i> | | Georgia (Russia), manganese | |
| <i>steel.</i> | | ores | 13, 15-6, 20-2 |
| Duplex process, raw and manu- | | gin process for ferro-manganese . . | 87 |
| factured materials consumed | | Giridih coal-field | 194-200 |
| in | 330-358 | Gold Coast, manganese ores, 13, 15, 23-6 | |
| Duplex process, the working of | | graphite, India | 257 |
| the | 358-426 | Greece, magnesite deposits | 473-7 |
| blast-furnaces to hot metal | | Gurumahisani, hematite deposits . | 331 |
| mixer | 358-9 | | |

- | | PAGE | | PAGE |
|--|-----------------------------|--|----------------|
| HARDNESS, of low-carbon iron-manganese alloys..... | 115-7, 124-5, 128, 134, 135 | modifying metals..... | 241-251 |
| hausmannite | 43 | refractory materials..... | 251-264 |
| hematite, India..... | 183-9, 331-4 | subsidiary minerals..... | 264-7 |
| Hofer process for ferro-manganese | 87 | operating companies..... | 268-279 |
| hydromagnesite, Canada..... | 466 | iron, low-carbon alloys of..... | 93-162 |
| | | see under <i>low-carbon alloys</i> . | |
| <i>Impact Resistance of Steels at Low Temperatures, The</i> (I. F. Morrison and A. E. Cameron), 533-551 | | iron and steel, production, India.. | 170 |
| previous work..... | 534-7 | “ “ imports, India..... | 170 |
| the present investigation.... | 537 | iron-ore, imported to Canada.... | 553 |
| steels investigated..... | 538 | “ India..... | 174-190, 331-4 |
| preparation of Charpy specimens..... | 538 | “ Lake Superior district.. | 22 |
| heat treatment..... | 539 | iron pyrite, India..... | 266 |
| atmospheric temperatures... | 540 | Italy, magnesite deposits of..... | 473 |
| experimental results..... | 540 | | |
| description of results..... | 542-9 | JAPAN, manganese ores of..... | 31 |
| conclusions..... | 550 | jhama..... | 230-1 |
| imports, ferro-manganese, Canada..... | 17 | Jharia coal-field..... | 201-9 |
| “ “ United States..... | 33, 40 | | |
| “ iron and steel, India.... | 170 | KANDRI manganese mine, India, 29-30 | |
| India, iron and steel production. | 170 | kaolin, India..... | 256 |
| “ magnesite..... | 477-9 | Kirthyana and iron works..... | 169 |
| “ manganese ores... 13, 15, 29-31 | | | |
| <i>India, The Manufacture of Steel by the Duplex Process in</i> (B. Yaneske)..... | 281-434 | LAKE Superior district, iron ores of..... | 22 |
| see under <i>manufacture of steel</i> . | | lateritic ores, India..... | 179-180 |
| Indian Iron & Steel Co., Ltd., plant and operations of..... | 275-9 | limestone, India..... | 236-239, 335-8 |
| Indian Iron & Steel Co., Ltd., minor ref..... | 168 | lithomarge, India..... | 256 |
| <i>India's Resources in Raw Materials for a Domestic Iron and Steel Industry</i> (Cyril S. Fox), 163-279 | | <i>Low-carbon Alloys of Iron and Manganese</i> (Sir Robert Hadfield, Bt.)..... | 93-162 |
| history..... | 164 | previous research..... | 96-111 |
| the agrarian industry..... | 165 | Terre-Noire investigations... | 101-6 |
| early European efforts..... | 166 | objects of the research..... | 111-7 |
| the existing industry..... | 167 | production of the alloys used..... | 117-120 |
| imports of iron and steel... | 170 | mechanical qualities..... | 122-6 |
| mineral production, 1911-25. | 172 | comparison with alloys of other investigators.... | 126-137 |
| chief raw materials..... | 173 | magnetic and electrical qualities..... | 137-145 |
| iron-ore occurrences..... | 174-189 | critical ranges on heating and cooling..... | 145-153 |
| iron-ore reserves..... | 189 | photomicrographs..... | 153-6 |
| coking-coal fields..... | 190-218 | corrodibility..... | 156-8 |
| reserves of coking-coal..... | 216-8 | discussion of results..... | 158-160 |
| other coals..... | 218-9 | conclusion..... | 160-2 |
| reserves of all coal..... | 220-2 | | |
| use of pulverized fuel..... | 222 | MADGEBRENT, composition of... | 459 |
| cleaning of coal..... | 225-7 | magdolite, composition of..... | 459 |
| carbonization methods.... | 227-232 | magnesia, properties of..... | 442-455 |
| fluid fuel from coal..... | 232-4 | melting point..... | 442 |
| fluxes..... | 234-241 | specific gravity..... | 443 |
| | | hydration..... | 445-7 |
| | | resistance to slag action..... | 448 |
| | | electrical resistivity..... | 449 |
| | | thermal conductivity..... | 450 |
| | | thermal expansion..... | 451 |
| | | hot crushing strength..... | 453-5 |

- | | PAGE | | PAGE |
|---|-----------------|---|------------|
| magnesia refractories, applica- | | pure manganese and its | |
| tions of..... | 482-505 | history..... | 49-52 |
| open-hearth furnaces..... | 482-6 | production of the metal..... | 52-5 |
| furnace bottoms..... | 487-492 | properties of the metal..... | 56-8 |
| roofs and walls..... | 492-8 | alloys of iron and manganese..... | 58-60 |
| ports, uptakes, etc..... | 498-9 | history of ferro-manganese..... | 60-84 |
| regenerators..... | 500-1 | manufacture of ferro-man- | |
| banks..... | 501 | ganese..... | 84-90 |
| ladles..... | 502 | carbon-free ferro-manganese..... | 90-2 |
| water cooling..... | 503 | manganese ores, Brazil..... | 14 |
| converters..... | 504 | “ Canada..... | 16-7 |
| ferro-alloy furnaces..... | 504 | “ Georgia | |
| <i>Magnesia Refractories for Steel</i> | | (Russia)..... | 15-6, 20-2 |
| <i>Furnaces</i> (G. M. Carrie and | | “ Gold Coast 13, 15, 23-6 | |
| C. F. Pascoe)..... | 435-521 | “ India, 13, 15, 29-31 | |
| historical..... | 436 | 244-8, 334 | |
| nomenclature..... | 437-9 | “ Japan..... | 31 |
| uses of magnesite..... | 439-442 | “ Mexico..... | 31 |
| properties of magnesite..... | 442-455 | “ Newfoundland.. | 17 |
| refractories available..... | 456-481 | “ South Africa.... | 27-8 |
| applications of magnesite re- | | “ South America.. | 32 |
| fractories..... | 482-505 | “ United Kingdom | 14 |
| summary..... | 505-517 | “ United States... | 17-8 |
| bibliography..... | 517-521 | manganese-magnesium-silicon... | 60 |
| magnesite, Australia..... | 479-481 | manganite..... | 43 |
| “ Austria..... | 461-5 | <i>Manufacture of Steel in India by</i> | |
| “ Canada..... | 465-8 | <i>the Duplex Process, The</i> (B. | |
| “ Cyprus..... | 481 | Yaneske)..... | 281-434 |
| “ Greece..... | 473-7 | development of the Tata iron | |
| “ India..... | 258, 339, 477-9 | and steel works..... | 282-303 |
| “ Italy..... | 473 | future developments..... | 303-8 |
| “ Manchuria..... | 471 | description of the Duplex | |
| “ Norway..... | 472 | plant..... | 308-330. |
| “ photomicrographs... | 512-5 | raw and manufactured mat- | |
| “ South Africa..... | 481 | erials consumed..... | 330-358 |
| “ United States..... | 469-471 | the working of the Duplex | |
| “ uses..... | 439-442 | process..... | 358-426 |
| magnesite bricks, Tata plant.... | 340 | conclusion..... | 427-434 |
| magnesium metal..... | 441 | masurium..... | 51 |
| “ salts..... | 441 | melting point of manganese..... | 57 |
| magnetic qualities of low-carbon | | merchant mill, Tata plant..... | 296 |
| iron-manganese alloys, 124-5, 137, 153 | | Mexico, manganese ores of..... | 31 |
| magnetite ores, India..... | 177-9 | mica schist, used in Tata plant... | 342 |
| magnite, composition of..... | 459 | micro-structure, low-carbon iron | |
| Manchuria, magnesite deposits of | 471 | manganese alloys..... | 153-6 |
| manganese, low-carbon alloys of, 93-162 | | “ magnesite..... | 512-5 |
| see under <i>low-carbon alloys</i> . | | “ steel..... | 542-550 |
| <i>Manganese, the Ores and the Metal;</i> | | Minas Geraes, manganese ore | |
| <i>with an account of the History</i> | | from..... | 23 |
| <i>and Production of Ferro-man-</i> | | mixer slag, analysis of..... | 361 |
| <i>ganese</i> (Sir Robert Hadfield, | | molybdenite, India..... | 243 |
| Bt.)..... | 1-92 | monazite, India..... | 250, 261 |
| manganese and its properties | 7-58 | NEWFOUNDLAND, iron ore, Can- | |
| history..... | 7-13 | adian imports of, 1926 | 553 |
| ores of manganese..... | 13-14 | “ manganese ores of..... | 17 |
| distribution of ores..... | 14-45 | Norway, magnesite deposits of... | 472 |
| world's production..... | 38 | “ smelting titaniferous | |
| uses and applications..... | 45-9 | ores of..... | 573-8 |

	PAGE		PAGE
OPEN-HEARTH furnaces, Tata plant.....	317-322	slag, analyses, open-hearth.....	416-7
oxychloride cement.....	440	“ “ salamander.....	382
PAINT, cold water.....	441	<i>Smelting Titaniferous Ores of Iron</i>	
photomicrographs, low-carbon iron-manganese alloys.....	153-6	(Alfred Stansfield.....)	552-578
“ magnesite.....	512-5	introduction.....	552-4
“ steel, 545, 546, 548-9		Canadian deposits.....	554-5
pig-casting plant, Tata.....	312-3	nature of the ores.....	555
pig-iron, for Tata Duplex plant.....	354-6	magnetic concentration.....	555
“ production, Canada, 1926.....	553	old smelting practice.....	556
pitchblende, India.....	248	smelting discontinued.....	557
plate mill, Tata plant.....	293-5, 307	experiments of Rossi.....	558
platinum ores, new elements in... 51		recent experiments.....	559-563
poora koela.....	190, 228-230	research of W. M. Goodwin.....	563-4
producer gas, at Tata plant.....	351	Bachman blast-furnace test.....	564-6
psilomelane.....	13, 43	smelting magnetites.....	566
pulp and paper industry, magnesite used in.....	440	commercial possibilities.....	567
pulverized fuel, possible use of, in India.....	222	discussion.....	568-578
pyrite, India.....	266	soaking pits, Tata plant.....	288, 307
pyrolusite.....	13-42	South Africa, magnesite deposits.....	481
QUARTZITE, India.....	249, 259	“ “ manganese ores of.....	27-8
RAIL steel, Duplex charge for... 403-4		“ “ smelting titaniferous ores of.....	570
rail and structural mill, Tata plant.....	290-2, 307	South America, manganese ores of.....	32
Raniganj coal-field.....	209-213	South Tirody manganese mine... 30-1	
refractories, Canadian, development of.....	508	specific gravity of manganese.... 56	
“ for India's iron and steel industry... 251-264		specific heat of manganese..... 57	
“ magnesia, for steel furnaces.....	435-521	specific magnetism of low-carbon iron-manganese alloys.....	124-5, 141-4, 146
see also under magnesia refractories.		sphalerite, India.....	265
rhenum.....	51	spiegel.....	58, 59
rhodochrosite.....	43	“ for Tata Duplex plant.... 356	
rhodonite.....	43	spiegeleisen, United States production.....	40
'rimming' steel.....	424	<i>Steel, The Cascade Method of Pouring</i> (J. G. Morrow).... 522-532	
SALAMANDER slag, analysis.....	382	<i>Steel, The Impact Resistance of, at Low Temperatures.....</i>	533-551
sheet-bar and billet mill, Tata plant.....	292-3, 307	see under <i>impact resistance</i> .	
sheet mill, Tata plant.....	295-6, 307	<i>Steel, The Manufacture of, in India by the Duplex Process</i> 281-434	
silica, India.....	259	see under <i>manufacture of steel</i> .	
silica clay, used in Tata plant.... 344		steel, Charpy impact tests on.... 539	
silico-spiegel.....	58, 59	“ microstructure of.....	542-550
sillimanite, India.....	262	see also under <i>iron and steel</i> .	
slag, analyses, blast-furnace..... 359		“ production, European..... 19	
“ “ converter, 371, 373, 375, 378, 381, 382, 383		“ “ United States..... 19, 32	
“ “ mixer.....	361	“ “ world..... 20	
		structural steel, Duplex charge for.....	402-3
		Sulaipat, hematite deposits.....	332
		sulphur, India.....	266
		sulphuric acid plant, Tata.....	284
		syndlag, composition of.....	459
		synthol.....	232

	PAGE		PAGE
TATA, Iron & Steel Co., Ltd.		United States, ferro-manganese	
see especially under <i>manu-</i>		statistics.....	40
<i>facture of steel.</i>		“ magnesite de-	
number of employees.....	433	posits.....	469-471
plant and operations		“ manganese ores..	17-8
of.....	271-5, 281-434	“ manganese situa-	
products of.....	432	tion, recom-	
raw materials used by....	235	mendations of	
minor ref.....	167	committee re-	
Tchiaturi, manganese ores... 15-6, 20-2		garding.....	35-7
temperature, in steel-making		United Steel Corporation of Asia.	169
furnaces.....	486	uranium ores, India.....	248
Terre Noire Company, investiga-			
tions on manganese steel.....	101-6	VANADIUM, occurrence of, in	
tin-bar steel, Duplex charge for..	400-1	titaniferous ores	571, 572, 573-8
tin-stone, India.....	264	Vanadium ores, India.....	249
titaniferous ores of iron, smelt-			
ing.....	552-578	WAD.....	43
see under <i>smelting.</i>		waste heat boilers, Tata plant...	322
titanium ores, India.....	250	wolframite, India.....	243
tungsten ores, India.....	243	wootz.....	164
tuyeres, converter, Tata plant...	346-8	wulfenite, India.....	243
analyses.....	348		
life of.....	348, 386	ZINC blende, India.....	265
UNITED Kingdom, manganese ore	14	zirconia ores, India.....	251

TRENT UNIVERSITY



0 1164 0303146 5

TN5 .E6 1927 pt.4
Empire mining and metallurgical
congress
... Proceedings

DATE

206773

206773

